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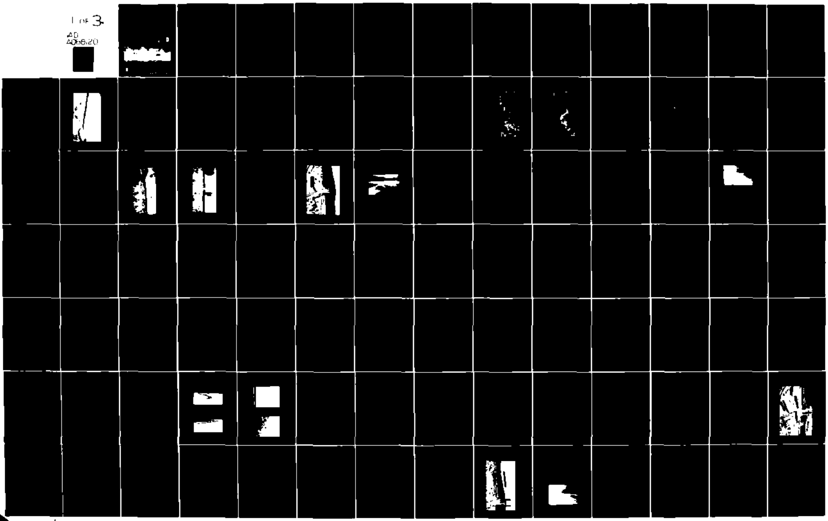

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TECHNICAL REPORT HL-80-9

LITTORAL PROCESSES STUDY, VICINITY OF SANTA ANA RIVER MOUTH FROM ANAHEIM BAY TO NEWPORT BAY, CALIFORNIA

by

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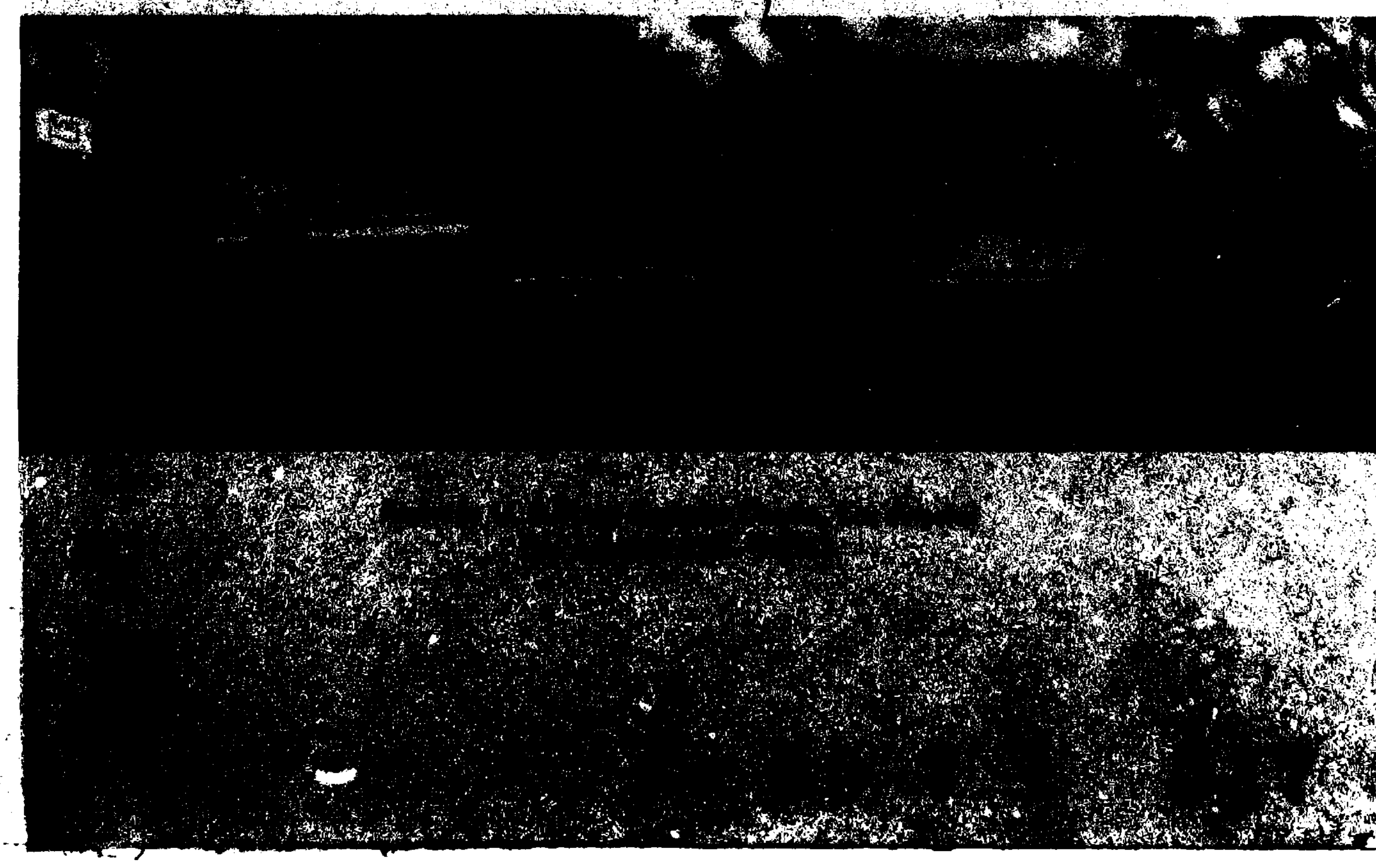

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Two separate but interrelated problems exist along the section of southern California coastline between Anaheim Bay and Newport Bay. These include: (a) erosion of the beach immediately east of Anaheim Bay (Surfside-Sunset Beach), and (b) determination of the optimum location and temporal distribution of one million (1,000,000) cu yd of material suitable for beach nourishment that will be excavated during the deepening and widening of the Santa Ana

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20. ABSTRACT (Continued).

River flood-control channel. Two additional closely aligned tasks were investigated: They include: (a) the hydraulic design of a tidal flow system to allow for flooding and emptying of a marsh habitat development area immediately north of the Pacific Coast Highway (on the east side of the Santa Ana River), and (b) the development of potential alternative feasibility concepts for maintaining an opening at the mouth of the Santa Ana River to allow passage of tidal flow up the river to the habitat area. Complete closure of the exit of the river now occurs as littoral material is trapped between the jetties, particularly during the summer months when riverflow is minimal. The habitat development area is being proposed to mitigate the loss of wildlife habitat resulting from the planned widening of the Santa Ana River (8 acres), and for preservation in response to the mandate of the Endangered Species Act (84 acres). The utilization of as much of this excavation material as possible for beach nourishment purposes is highly desirable.

It was determined that because of the sheltering effects of the offshore islands, the general orientation of the coastline, the large shoal region in front of San Pedro Bay, and the nearness of the Newport Submarine Canyon to the shoreline, significant variations in littoral drift occur with distance along the coast in this region. The Surfside-Sunset Beach region is experiencing a net southerly drift of approximately 276,000 cu yd per year; Huntington Beach region (including the vicinity of the Santa Ana River mouth) is losing approximately 112,000 cu yd net per year in a southerly direction; that region south of the Newport Submarine Canyon is experiencing a net southerly movement of approximately 127,000 cu yd per year. The Huntington Beach region will continue to be nourished naturally as long as the feeder beach at Surfside-Sunset Beach is maintained.

Feasibility conceptual alternatives for providing unrestricted tidal exchange through the mouth of the Santa Ana River were considered, their probability of success was qualitatively deduced, and an order-of-magnitude estimate of their installation cost was approximated. These concepts included river jetty extensions, floodgates, pipelines, jet pump sand bypassing systems, and hydraulic structures. It was determined by Keulegan's approximation, and confirmed by one-dimensional numerical techniques, that a variety of concrete gated pipes and culverts could be installed that would effectively transmit approximately 98 percent of the tidal prism necessary to induce maximum bay water-surface elevation, a requirement dictated by the necessity to ensure a precise bay water-surface rise and fall with the lunar ocean tide of the region.

The wide beach immediately to the west of the Santa Ana River should not be adversely affected by the extensions of impermeable river jetties into the surf zone for the purpose of preventing the accumulation of littoral drift material in the mouth of the river. The potential jetty extensions would also provide a cell for the placement of a large portion of the material to be excavated from the flood channel (between the east jetty extension and the westernmost groin of the Newport Beach groin field). Significant amounts of material could also be placed inside the groin field itself.

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PREFACE

Parts I-IV and VI-VII of the study reported herein were requested by letter of 13 November 1979 from U. S. Army Engineer District, Los Angeles (SPL), to U. S. Army Engineer Waterways Experiment Station (WES), and were subsequently authorized by Intra-Army Order Number CIV-80-18 for Reimbursable Services dated 27 November 1979. Part V of this study was requested by SPL to be performed through the auspices of the Dredging Operational Technical Support Program (DOTS) sponsored by the Office, Chief of Engineers, and managed by the Environmental Laboratory (EL) of WES.

This study was conducted during the period 15 December 1979 through 29 February 1980 by personnel of the Hydraulics Laboratory of WES under the general supervision of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory; Mr. F. A. Herrmann, Jr., Assistant Chief of the Hydraulics Laboratory; Dr. R. W. Whalin, Chief of the Wave Dynamics Division; Mr. D. D. Davidson, Chief of the Wave Research Branch; and Mr. C. E. Chatham, Jr., Chief of the Wave Processes Branch. Dr. L. Z. Hales, Research Hydraulic Engineer, Hydraulics Laboratory, performed the investigations described herein and prepared this report. Ms. Fala Powers and Messrs. Tad Nizinski, William Van Peeters, and Claude Wong were the SPL Technical Monitors during the preparation and publication of this report.

Mr. C. J. Newling, DOTS team member of EL, contributed to the investigation described in Part V of this report concerning the marsh habitat development phase of the Santa Ana River Project. Mr. Newling developed conceptual designs of artificial marsh habitats and assisted in coordination efforts between SPL and WES personnel regarding the hydraulic design alternatives for accomplishing inundation of the proposed marsh.

Commander and Director of WES during the conduct of the investigation and the preparation and publication of this report was COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acre-feet	1233.482	cubic metres
acres	0.4047	hectares
cubic feet	0.02831685	cubic metres
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
fathoms	1.8288	metres
inches	25.4	millimetres
knots (international)	0.5144444	metres per second
miles (U. S. statute)	1.609344	kilometres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
square miles (U. S. statute)	2.589988	square kilometres
tons (2000 lb, mass)	907.1847	kilograms

LITTORAL PROCESSES STUDY, VICINITY OF SANTA ANA RIVER MOUTH FROM ANAHEIM BAY TO NEWPORT BAY, CALIFORNIA

PART I: INTRODUCTION

Project Location

1. The region of southern California coastline encompassed by this study commences at approximately the eastern end of the Los Angeles-Long Beach Harbor complex (Anaheim Bay east jetty) and extends east and southeasterly for a distance of approximately 17 miles* to the Newport Bay-Newport Beach area (Figure 1). This region is so distinctly separated from the adjacent coastlines by Point Fermin on the north and the Newport Submarine Canyon on the south that it can be effectively considered as a littoral cell, referred to as the San Pedro Littoral Cell by Inman (1976). The direction of net longshore transport of material in this vicinity is considered to be southerly by most researchers, for example Emery (1960), Shepard and Wanless (1971), and Inman (1976). Any material that may be drifting south past Point Fermin will be deposited in the deep water in San Pedro Bay outside the Los Angeles-Long Beach Harbor breakwaters. Correspondingly, any littoral material drifting south past Newport Beach will vanish from the system as it is either moved offshore into deep water or trapped by Newport Submarine Canyon.

2. A littoral cell is defined as a coastal segment that contains a complete sedimentation cycle including sources, transport paths, and sinks. This region of coastline satisfies these requirements; i.e., the source being the feeder beach located immediately east of Anaheim Bay (Surfside-Sunset Beach) and infrequent transport to the beach by flooding of the Santa Ana River, the transport path being the surf zone energized by breaking waves, and the ultimate sink to the south being

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

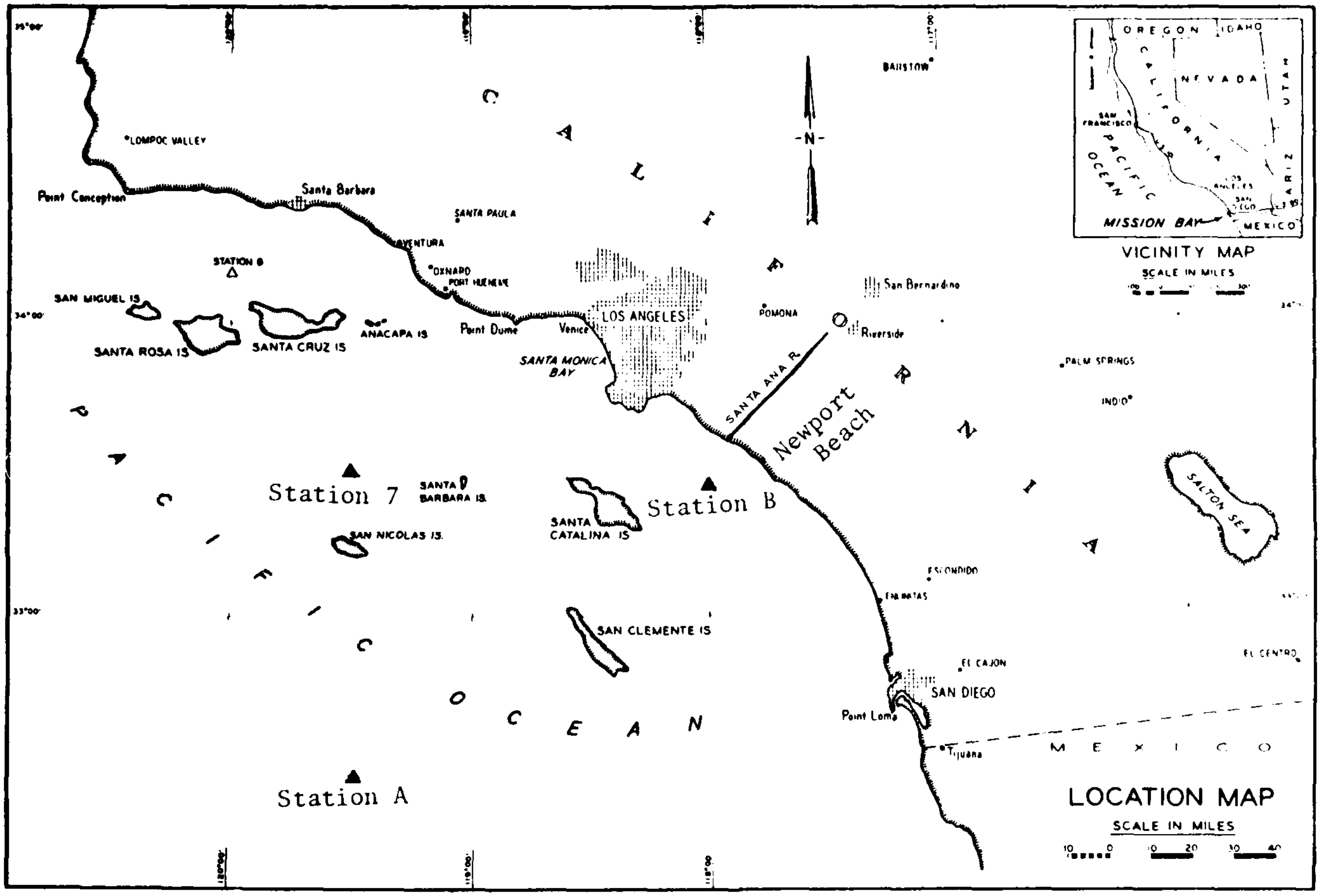

Figure 1. Project location, Santa Ana River mouth region and littoral cell extending from Los Angeles to Newport Beach

either the Newport Submarine Canyon or the steeper nearshore bathymetry in the Newport Beach region. No firm quantitative figures exist to state precisely what happens to the sand, and this question has contributed to the establishment of a monitoring program by U. S. Army Engineer District, Los Angeles. Sinks also exist to the north in the form of Anaheim Bay (for material potentially transported into the bay by tidal currents) and the beaches sheltered by the Long Beach breakwaters from wave energy which could transport material back to the south. Sources of material for transport to the north are the beaches along the entire cell and infrequent transport to the beach by the Santa Ana River.

3. The Santa Ana River enters the Pacific Ocean at approximately the midpoint of the littoral cell and has historically contributed a significant amount of sediment to the surf zone. An analysis of U. S. Geological Survey sediment discharge data for the Santa Ana River for the period 1941-1971 by Kroll (1975) indicated the mean annual volume of coarse-sediment discharge to be 190,000 cu yd of material. However, in recent years, periods of prolonged drought and the construction of floodwater retarding structures on the river have drastically reduced the amount of river-transported sediment to the ocean. Reduction in the supply of sand to the beaches has resulted in beach erosion which has necessitated extensive beach nourishment (Los Angeles District 1978a).

Statements of the Problems

4. Two distinct but interrelated problems exist near the mouth of the Santa Ana River and along the adjacent shoreline. The major problems of this region include: (a) erosion of the beach immediately east of Anaheim Bay (Surfside-Sunset Beach), and (b) optimum location and temporal distribution of up to one million (1,000,000) cu yd of material suitable for beach nourishment from the widening and deepening of the Santa Ana River flood-control project. In addition to these major problems, two associated tasks exist: (a) hydraulic design of a tidal flow system to allow for the flooding and emptying of a marsh habitat development area immediately north of the Pacific Coast Highway (on the

east side of the Santa Ana River), and (b) development of design feasibility concepts for maintaining an opening at the mouth of the Santa Ana River to allow passage of tidal flow up the river to the habitat area. Complete closure of the exit of the Santa Ana River now occurs as littoral material is trapped between the jetties, particularly during the summer months when riverflow is minimal. The habitat area is being developed to mitigate the loss of 8 acres of wildlife areas resulting from the planned widening of the Santa Ana River, and to preserve 84 additional acres in response to the mandate of the Endangered Species Act. Utilization of as much of this excavation material as possible for beach nourishment purposes is highly desirable.

Purpose of the Study

5. In order to ascertain the proper location and placement time for a large amount of beach nourishment material, it is necessary to determine the temporal distribution of potential longshore movement of littoral material in the surf zone of this region. Because of the large extent of coastline involved (approximately 17 miles), it is desirable (and convenient because of shoreline orientation) to isolate three separate sections and determine, on the average, the amount of material that is potentially being transported along each section by the incoming surface gravity wave climate. Accordingly, the U. S. Army Engineer Waterways Experiment Station (WES) was requested to apply the latest statistical wave data for this region, to estimate the potential longshore transport of littoral material, and to recommend the time and location of the placement of up to one million cu yd of material along the beaches of this area. These data will be incorporated into an analysis of potential alternative solutions for ensuring a permanent opening at the mouth of the Santa Ana River to allow passage of a tidal prism for the marsh habitat development area. The preliminary hydraulic design of the structures for passage of this tidal prism into the habitat area was also requested, based on the biological requirements of the salt marsh vegetation under consideration.

PART II: BEACH MAINTENANCE, ANAHEIM BAY TO NEWPORT BAY

6. The supply of beach nourishment material to the San Pedro littoral cell has been severely restricted in recent years by the construction of dams and debris basins on the Los Angeles, San Gabriel, and Santa Ana Rivers. While the Los Angeles-Long Beach Harbor breakwaters prevented much of the material transported into the harbor by the Los Angeles River from being carried downcoast, some of the sediments transported by the San Gabriel River could pass by Anaheim Bay and nourish the Surfside-Sunset Beach area prior to the construction of the Anaheim Bay jetties. Erosion of the shoreline at Surfside-Sunset Beach has been a relatively continuous problem since the mid-1940's, according to the Los Angeles District (1978a) (Figure 2). In 1945, the U. S. Navy constructed 600 ft of stone revetment downcoast from the Anaheim Bay east jetty to retard the erosion but had to reinforce it the following year. In 1947, the revetment was further extended and a wood sheet-pile bulkhead established to strengthen the shore road. Throughout the 1940's, material in the amount of 1,422,000 cu yd was placed on the beach. Additional material placed along the Surfside-Sunset Beach shoreline later included 874,000 cu yd in 1956, 4,000,000 cu yd in 1964, and 2,300,000 cu yd in 1971.

7. The bathymetry of this region, and the sheltering effect of the offshore Islands of San Clemente, Santa Catalina, San Nicolas, and Santa Barbara, is such that waves generated in the open ocean can approach the coast in this region only from the due-west sector and the south-to-southeast sector. The Surfside-Sunset Beach region is more protected from southerly waves than is Newport Beach. Hence, the amount of material transported to Surfside-Sunset Beach from the south is less than that at Newport Beach. Simultaneously, the orientation of the beach at Newport Beach is such that the divergence of wave energy from the west does not transport nearly as much material in a southerly direction here as at Surfside-Sunset Beach. The result is that a loss of material is being experienced at Surfside-Sunset Beach which consists of a net downcoast littoral movement of about 276,000 cu yd per year. Additionally,

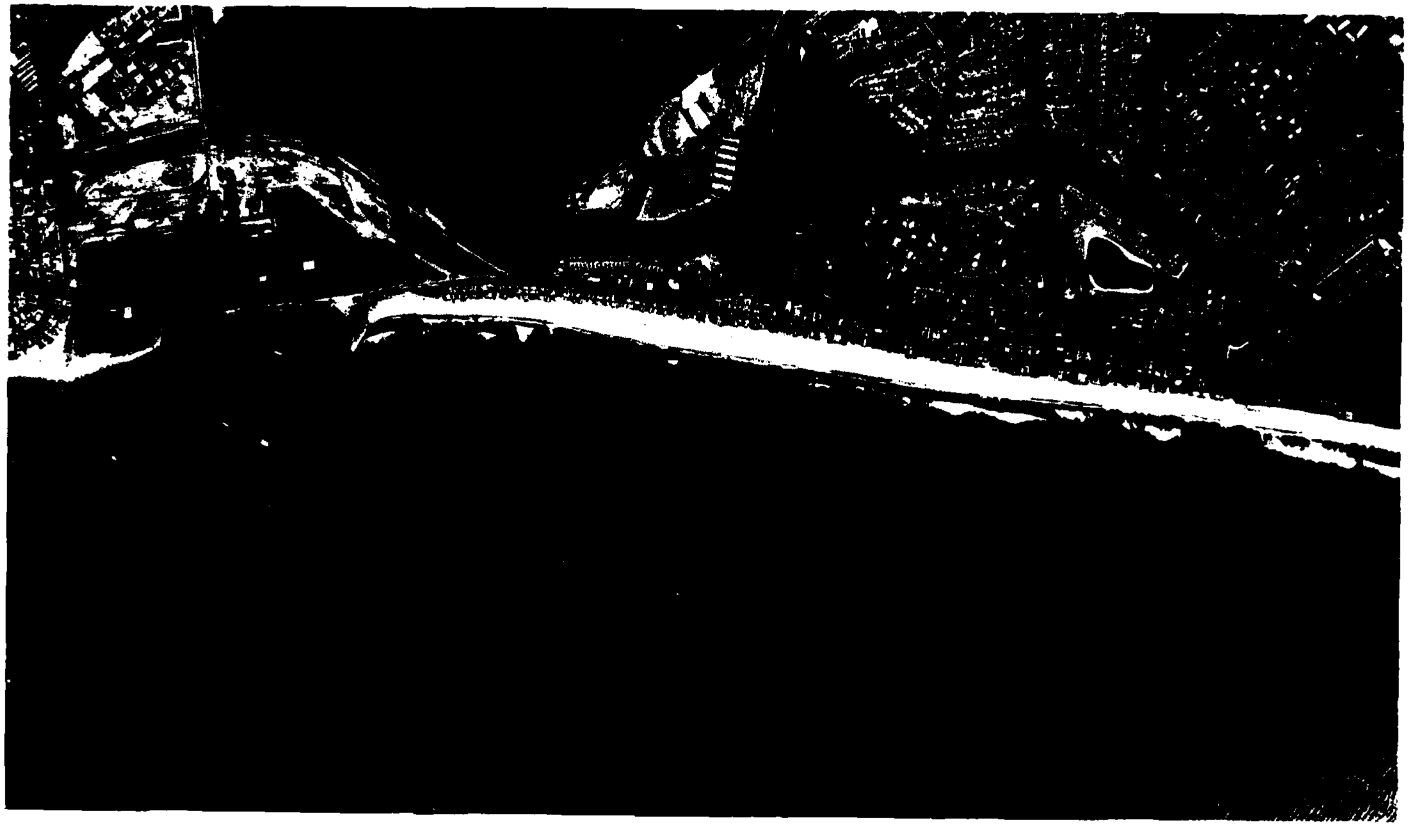

Figure 2. Anaheim Bay to Surfside-Sunset Beach, California. The section of beach adjacent to the east jetty and for a distance of approximately 6,000 ft eastward serves as a feeder beach to nourish the downdrift beaches of Huntington Beach and Newport Beach

a volume of material estimated at about 25,000 cu yd per year is being trapped by the Anaheim Bay east jetty and is prevented from returning to the system. This 25,000 cu yd per year is relatively insignificant when compared with the volume of sediment placed periodically on the beach. The overwhelming majority of the material placed on the beach is being gradually transferred downcoast and eventually out of the system.

Beach Nourishment Project

8. The project for beach nourishment and protection from Anaheim Bay east jetty to Newport Bay was authorized by Act of Congress, Public Law 87-874, 87th Congress, 2d session, approved 23 October 1962 in accordance with House Document 602, 87th Congress. The plan set forth in the project document provided for improvements consisting of construction of a single detached offshore rubble-mound breakwater, about 2,600 ft long and located along the -24 ft mllw contour just upcoast from the Newport Beach fishing pier, and the deposition of approximately 3,000,000 cu yd of suitable beach-building material along the upper Orange County shoreline in the vicinity of Surfside and Sunset Beach. On 13 September 1963, the Chief of Engineers authorized the existing project to be modified as the result of a request by local interests and a reevaluation of basic data. The modified project consists of: (a) relocating the proposed breakwater near the mouth of the Santa Ana River, (b) extending the south jetty at the Santa Ana River, (c) constructing groins and fills between the Santa Ana River and Newport pier at such time and in such locations as required, and (d) increasing the sand to be placed at Surfside-Sunset Beach from 3,000,000 cu yd to 4,000,000 cu yd. The modified project is being constructed in stages as required.

Stage 1

9. This portion of the project, which was completed in June 1964, provided for the placement on the beach in the Surfside-Sunset Beach area of 4,000,000 cu yd of sand dredged from the U. S. Naval Weapons Station Harbor. Development of the feeder beach, approximately 500 ft

wide and 10,000 ft long, has provided downcoast movement of material from the beach that serves to nourish and stabilize the remaining segment of shoreline to the Santa Ana River.

Stage 2

10. This element was accomplished under two contracts, the first of which was completed in February 1968 and included the placement of 494,000 cu yd of sand on the beach between 32d and 50th Streets at Newport Beach, and the construction of a 250-ft-long steel test groin at 40th Street. The second contract, completed in November 1968, provided an additional 246,000 cu yd of sand in the above area and included the construction of a 191-ft-long steel groin at 44th Street and a 60-ft-long steel groin at 48th Street.

Stage 3

11. The third stage of construction consisted of four rubble-mound groins at 36th, 48th, 52d, and 56th Streets with lengths of 507 ft, 340 ft, 340 ft, and 570 ft, respectively, and was completed in November 1969. The area from the mouth of the Santa Ana River to 36th Street in Newport Beach was filled with a total of 750,000 cu yd of sand hauled from the Santa Ana River channel by authority of Public Law 99, 84th Congress. The work was completed in February 1970.

Stage 4

12. The item of work included in Stage 4 consisted of the placement of 2,300,000 cu yd of material dredged from the U. S. Naval Weapons Station Harbor, and was used to restore the feeder beach (500 ft wide by 6,000 ft long) at the Surfside-Sunset Beach area. This work was completed in May 1971.

Stage 5

13. The fifth stage of the authorized project provided for the encasement with rock of two steel sheet-pile test groins at 40th and 44th Streets to lengths of 480 ft and 470 ft, respectively. Two additional rubble-mound groins were built at 28th and 32d Streets with lengths of 600 ft and 540 ft, respectively. Construction of a 590-ft rubble-mound groin at 62d Street was deferred pending a demonstrated need. In addition to the rubble-mound groin construction, 358,000 cu yd

of sandy beach nourishment material was placed on the beach to restore eroded areas and to prevent downbeach starvation. This work was completed in March 1973.

Stage 6

14. This stage provides for the construction of an offshore breakwater immediately upcoast from the mouth of the Santa Ana River to act as a sand trap to halt further downcoast movement of beach material, which would then be pumped upcoast to restore the feeder beach system. Stage 6 also provides for the extension of the south jetty at Santa Ana River mouth; however, this stage of the project has been deferred pending a demonstrated need.

Stage 7

15. Because there is no natural supply of littoral material for the Surfside-Sunset Beach problem area, the beach requires periodic nourishment if it is to be preserved to dimensions adequate for protective and recreational purposes. The periodic nourishment requirement. have been based on analysis of volume changes from hydrographic surveys over a long period of time by Los Angeles District, U. S. Army Engineer Beach Erosion Board, and U. S. Coast and Geodetic Survey (1878, 1934, 1937, 1949, 1958, 1961, 1965, and 1979). These surveys show that on the average, around 300,000 cu yd of material is disappearing from the feeder beach region annually. The objective of Stage 7 of the authorized project was to restore the recreational beach and to protect the public and private improvements by replenishing the existing feeder beach at Surfside-Sunset Beach.

16. The use of Anaheim Bay as a source of this needed beach material would require dredging about 2,000,000 cu yd of material to obtain the 1,370,000 cu yd estimated for nourishment purposes. This would have been necessary because sample analysis of the material showed that the acceptable material is overlain by about 500,000 cu yd of unsuitable material (excessive fines). Environmental Protection Agency regulations require disposal of such unsuitable material at an approved offshore site, the nearest being about 9 miles from Anaheim Bay, and involving great transportation costs. Therefore, to reduce costs, an

alternative borrow area (4,600 ft x 1,800 ft) located approximately 6,500 ft offshore in front of Surfside-Sunset Beach was selected for obtaining the necessary material for nourishing the feeder beach. Stage 7 was completed in June 1979, as 1,644,000 cu yd of material was pumped onto the beach. This offshore borrow area also contains an additional estimated 2,000,000 cu yd of suitable material that can be utilized for the next beach nourishment project. Additionally, the offshore sand inventory of the continental shelf of southern California by the U. S. Army Engineer Coastal Engineering Research Center (CERC 1973) indicates that 220,000,000 cu yd of suitable sand exists in nearby areas. A summary of these placements is given in Table 1.

Monitoring Program

17. In compliance with the Federal Water Pollution Control Act Ammendments of 1972 (Public Law 92-500) and the Coastal Zone Management Act (EC 1165-2-121), a 5-year postconstruction monitoring program has been established by Los Angeles District to determine the effects of beach nourishment efforts along the Surfside-Sunset Beach region on the environment. The monitoring program will provide a data base by recording the effects on the physical and biological environment of the offshore excavation and massive deposition of sand on the beach. The data obtained will also be useful in determining the need to construct Stage 6 or to delete it from the project. The biological and physical effects of massive sand movement on the intertidal zone are not known for exposed shorelines in southern California; hence, the monitoring program will help to develop more effective methods of beach protection and nourishment.

Biological monitoring

18. The scope of the biological phase of the monitoring program consists of several study areas; the offshore borrow site (approximately 6,500 ft offshore in front of Surfside-Sunset Beach), the intertidal zone, and the subtidal disposal region. The sampling at the borrow site consists of 15 benthic stations (diver cores and observations) and 3

trawl stations. The sampling of the disposal sites consists of nine diver transects perpendicular to shore (clamming and observations) and nine intertidal clamming stations. Data collections are taking place twice yearly (summer and fall).

Physical monitoring

19. To determine the direction of approach of incident waves and to provide improved estimations of the longshore sand transport, a 4-gage directional array, at a depth of approximately 30 ft of water, will be installed (Los Angeles District 1978b). The gages (low energy transducers) will be located downcoast of the borrow area (6,000 ft offshore) and will be connected by cable to shore. Transducers will be calibrated for the 4- to 20-sec period wave range, with the information being recorded at 10-hr intervals and transmitted by telephone lines to a central computer center.

20. To determine the general, deepwater wave climate, without the effects of refraction, a wave rider buoy will be placed at the 200-ft deepwater location, directly offshore from the directional array. This buoy will also be calibrated for the same range of wave conditions. The wave gaging phase of the physical monitoring program will help to establish better wave information for this region, and will augment a numerically directional spectral wave climatology study currently under way by Resio (in preparation). In the meantime, results of this data collection phase will add another source of data to the presently existing hindcast information frequently used by coastal engineers in this region (National Marine Consultants 1960; Marine Advisers 1961; and Meteorology International, Inc. 1977).

21. The entire beach between Anaheim Bay and Newport Bay (about 90,000 ft) will have hydrographic and topographic surveys repeated on a quarterly basis for the duration of the 5-year program. This will include a total of 70 profiles to depths of 36 ft mllw. The first 6,000 ft of shoreline immediately south of the Anaheim Bay east jetty will have profiles spaced 500 ft apart. The next 50,000 ft of shoreline will have profiles spaced 1,000 ft apart, and the remaining 34,000 ft of shoreline will have profiles spaced 5,000 ft apart. Provisions also will

be made for special surveys following extraordinary climatic events. The offshore borrow area will be surveyed quarterly with 20 ranges spaced 200 ft apart, and with each range being 6,600 ft in length. Supplemental preconstruction surveys near the mouth of the Santa Ana River with a spacing not to exceed 500 ft would be of great value in analyzing post-construction effects of the proposed improvements to the Santa Ana River mouth.

22. Preconstruction sand samples of the borrow and disposal areas were obtained, and postconstruction samples of these regions will be obtained on a twice-yearly basis, with mechanical analyses being run on each one. Analysis of this material for median grain size and distribution will help determine the correlation between the natural beach material and the borrow material, and thus better define the sorting process on the open coast. To accomplish this task, 25 ranges will have sand samples taken at elevations of +12 ft, +5 ft, 0, -6 ft, -12 ft, -18 ft, -24 ft, and -30 ft mllw. The samples will be mechanically analyzed with the same size sieves used by Hobson (1977) for corroboration of these previous data. The basic features of the coastline from Anaheim Bay to Newport Beach have been documented by California Department of Navigation and Ocean Development (DNOD 1977), Figures 3 and 4.

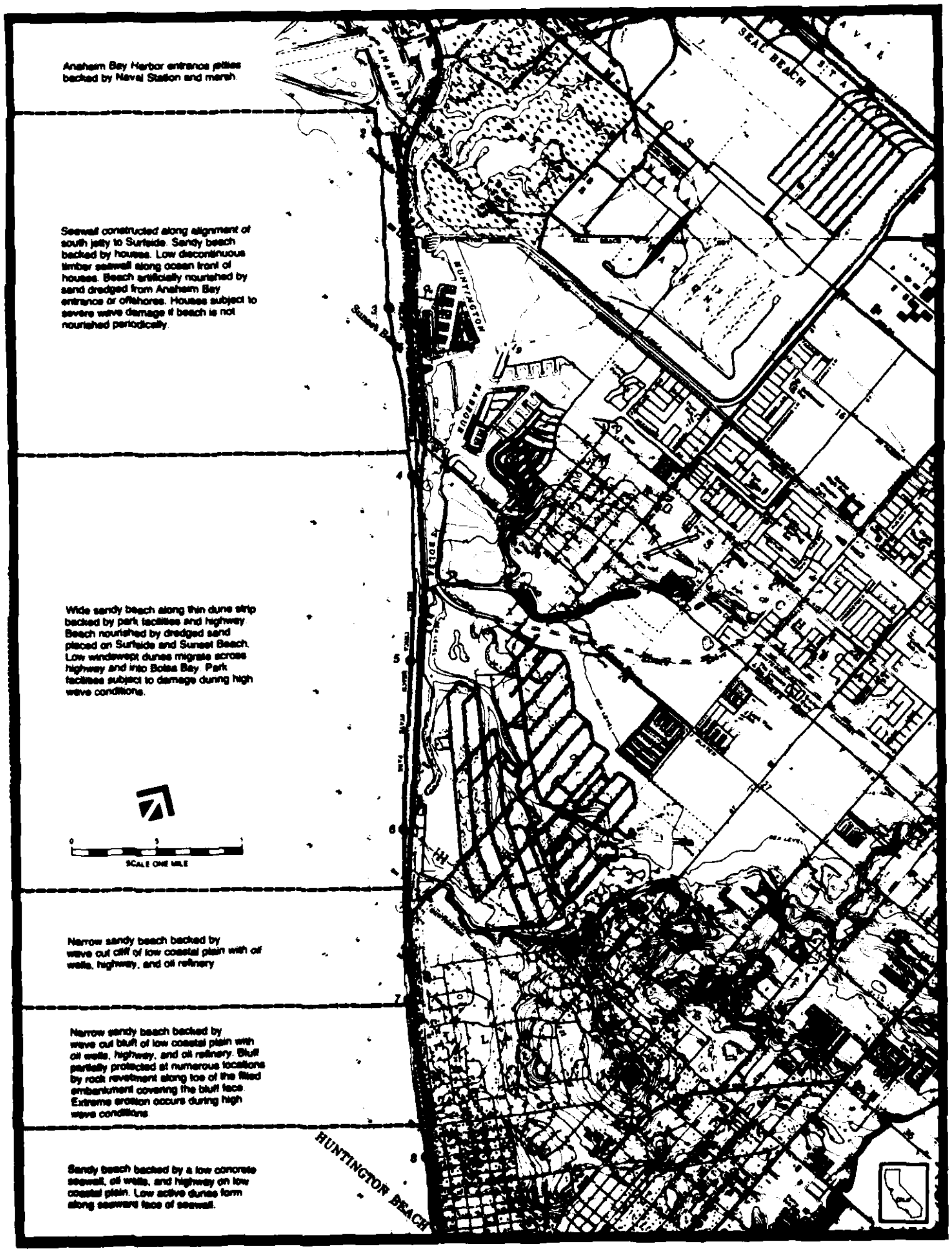

Figure 3. General shoreline characteristics, Anaheim Bay to Huntington Beach, California (after California Department of Navigation and Ocean Development 1977)

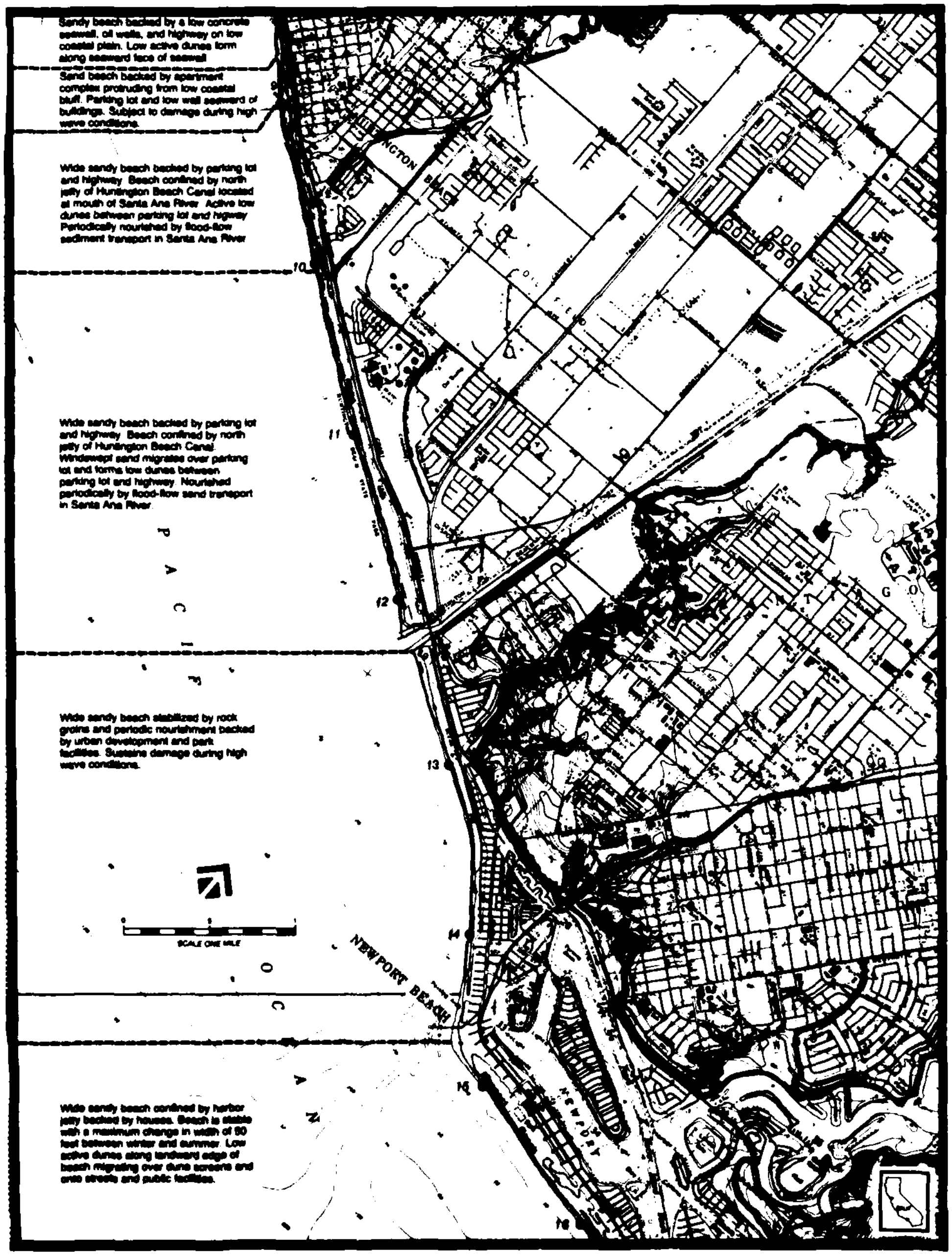

Figure 4. General shoreline characteristics, Huntington Beach to Newport Beach, California (after California Department of Navigation and Ocean Development 1977)

PART III: SANTA ANA RIVER FLOOD-CONTROL PROJECT

23. The Santa Ana River Basin, Figure 5, is the largest river system in southern California, with the basin study area encompassing a total of about 3,200 square miles. The Santa Ana River has its origin in the San Bernardino Mountains and flows some 80 miles west and south through San Bernardino, Riverside, and Orange Counties to the Pacific Ocean. A wide range of economic activities is carried on within the area. With the great migration of people into southern California during and after World War II, extensive urban development resulted in greatly increased urban runoff. As urbanization progressed in the Santa Ana River Basin, levees along the channel were raised and strengthened; and after the disastrous 1938 floods, Prado Dam was built in 1941 to provide Orange County protection from what was then considered to be a 200-year flood. Increased knowledge in the field of hydrology, and continuing urban growth above Prado Reservoir, led to recognition that Prado Dam and Reservoir are now inadequate and cannot control floods larger than a 70-year magnitude; and periodic floods which have carried tremendous quantities of sediment into the reservoir (sediment which is now prevented from reaching the Pacific coast beaches) have silted 25,000 acre-feet of the 223,000 acre-feet of original storage (Los Angeles District 1975). If a standard project flood were to occur today, property damages and economic losses estimated in excess of $4.5 billion would result (Los Angeles District 1979). There would be an uncontrolled flow of water 12 ft deep over the spillway of Prado Dam, and one million people living downstream from Prado would be severely flooded. The State of California has identified the Santa Ana River as one of the most significant flood problems in the entire State.

24. Over 60 potential alternative plans were developed in the Review Report on the Santa Ana River Main Stem including Santiago Creek and Oak Street Drain, referred to herein as the project's 1975 Survey Report. These potential alternative plans were developed to investigate all reasonably possible solutions to the flood problems of the Santa Ana River Basin, including floodproofing, permanent evacuation, and other

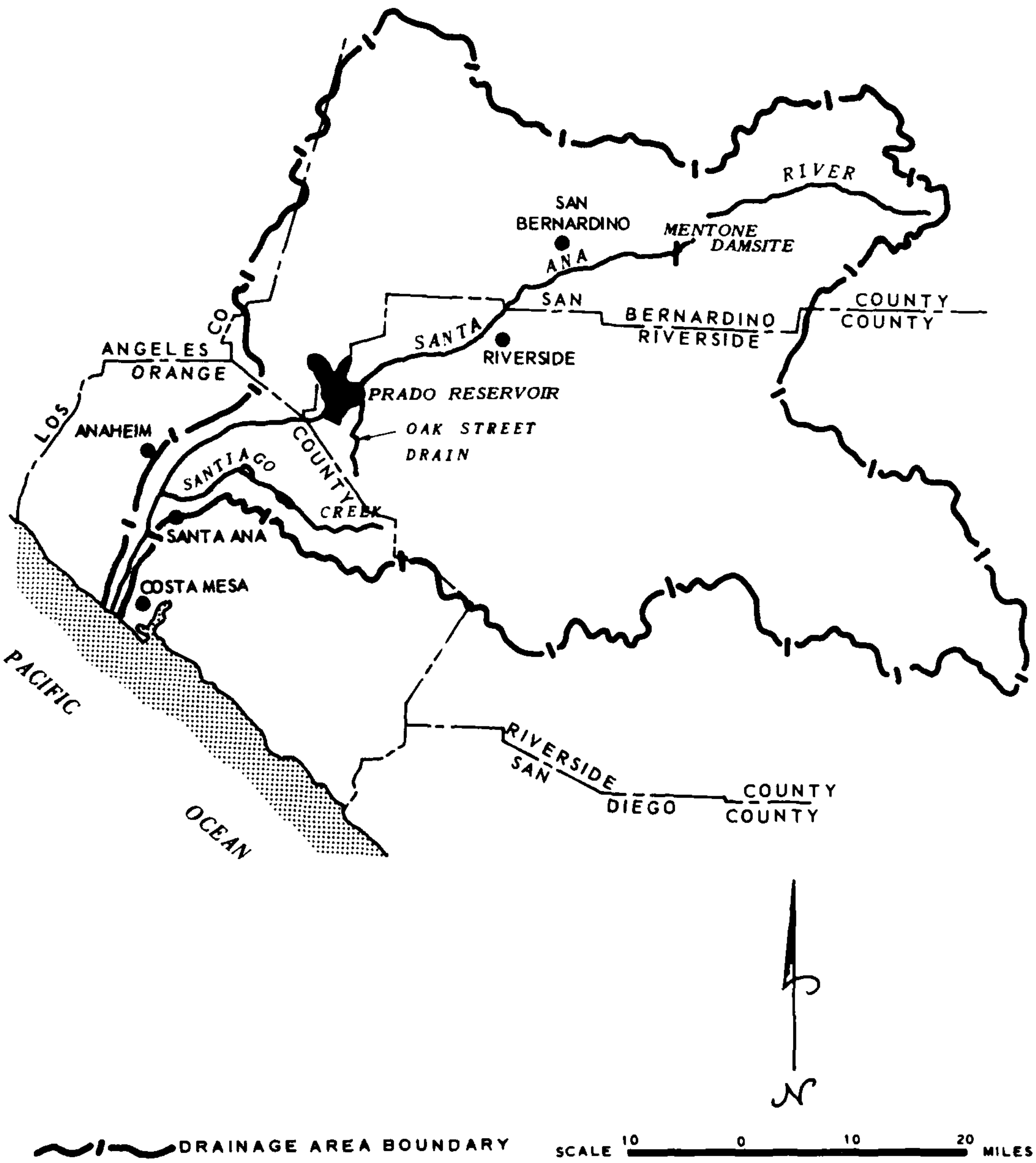

Figure 5. Santa Ana River Drainage Basin

land-use management approaches. Most of these alternatives failed to solve the problem at a reasonable cost. Long-term solutions involving greenbelts or large downstream channels were also studied, but such plans would displace from 2,700 to 7,400 homes and extract too high a social cost. Excavation of Prado Reservoir was infeasible because of the lack of a disposal site and the severe environmental impacts. From this array of over 60 alternatives, 9 engineeringly feasible alternative plans of action were selected as most viable and were evaluated in detail (Los Angeles District 1975). The Phase I General Design Memorandum study will reevaluate the 1975 Survey Report's recommended plan (the All-River Alternative) in light of changed conditions and criteria that have occurred during the past 5 years. This reevaluation will either reaffirm the recommended plan as the best plan for the area or reformulate and recommend a plan that better serves the area's needs.

Physiography of the Region

25. Of the total Santa Ana River Basin, approximately 2,255 square miles are above Prado Dam, which is the major flood-control structure on the river. Approximately 23 percent of the basin lies within the rugged San Gabriel and San Bernardino Mountains, about 9 percent lies in the San Jacinto Mountains, and about 5 percent is within the Santa Ana Mountains. Most of the remaining area is in the valleys formed by the broad alluvial fan along the base of these mountains. The Santa Ana River has an average gradient of about 240 ft/mile in the mountains, about 20 ft/mile near Prado Dam, and about 15 ft/mile below Prado Dam. The average gradient of the tributaries is about 700 ft/mile in the mountains and about 30 ft/mile in the valleys.

26. The entire Santa Ana River Basin is underlain by a basement complex of crystalline metamorphic and igneous rocks, which appear on the surface only in the mountainous parts of the area. In the foothills and valleys, the basement complex is overlain by a series of sandstones and shales. Unconsolidated alluvial deposits range in depth from a few feet at the base of the mountains to more than 1,000 ft on the cones and

in the valleys. The existence of several precipitous mountain ranges along the upper boundaries of the area indicates that the area has been subjected to extensive folding and faulting. The soils in the mountains, which are derived mainly from metamorphic and igneous rocks, are shallow and stoney. On the lower slopes of the mountains and in the foothills, the soils are mainly loams and sandy loams, ranging from less than 1 ft to 6 ft deep. In the valleys, where the soils are usually more than 6 ft deep, the surface soils range from light, sandy alluvium to fine loams and silty clays with heavier subsoils (Los Angeles District 1975).

Runoff characteristics

27. There are three types of storms that produce significant precipitation in the Santa Ana River Basin: (a) general winter storms, (b) general summer storms, and (c) intense local storms (Los Angeles District 1975). The general winter storms usually occur during the period from December through March. They originate over the Pacific Ocean as a result of the interaction between polar Pacific and tropical Pacific air masses and move eastward over the basin. These storms, which often last for several days, reflect orographic influences and are accompanied by widespread precipitation in the form of rain and, at higher elevations, some snow. The general summer storms in this area are usually associated with tropical cyclones and occur very infrequently. They are known to have occurred in the late summer and early fall months, but have not resulted in any major floods during the period of record. Local storms can occur at any time of the year, either during general storms or as isolated phenomena. Those that occur in the winter are generally associated with frontal systems. These storms cover comparatively small areas but result in high-intensity precipitation for durations of up to 6 hours.

28. Although historical references to flood conditions in the general region date back to about 1769, little information is available regarding the magnitude of floods prior to 1850. Recorded data from 1897 to the present show that medium-to-large winter floods occurred in 1903, 1910, 1914, 1916, 1921, 1922, 1927, 1938, 1943, 1965, 1966, and 1969. Since the historical floods of the 1800's and early 1900's,

considerable change has occurred in the drainage basin. The runoff characteristics of the majority of the valley area have been changed by urbanization and agriculture. The mountain areas have remained relatively unchanged; but several small reservoirs, detention dams, and debris basins have been constructed at the canyon mouths. If some of the big, historical storms occurred today, the mountain runoff would be about the same as that in the past because the small structures would have little effect on major floods on the main stem of the Santa Ana River above Prado Dam. The valley runoff would be considerably higher in both peak and volume because of the impervious areas of urbanization and channelized flow.

Standard project flood

29. The standard project flood represents the flood that would result from the most severe combination of meteorologic and hydrologic conditions considered reasonably characteristic of the geographic area. The standard project flood is normally larger than any past recorded flood in the area and would be exceeded in magnitude only on rare occasions. It thus constitutes a standard for design that would provide a high degree of flood protection (Los Angeles District 1975). The standard project storm for the Santa Ana River Basin was determined by Los Angeles District by evaluating several storms to ascertain the event that represents the most severe flood-producing rainfall, depth-area-duration relationship, and isohyetal pattern that is considered reasonably characteristic of the region. It was determined that a general storm would govern for all points under consideration on the Santa Ana River. Under certain project alternative evaluations where outflow from Prado Dam is limited, however, a local storm centered below Prado Dam was found to govern.

Maximum probable flood

30. The maximum probable flood is the flood that can be expected from the most severe combination of meteorologic and hydrologic conditions reasonably possible in the region. Probable maximum flood is an estimate of the upper boundary of flood potential for a drainage area. Such a hypothetical flood is required for redesigning the spillway for

Prado Dam and for designing the spillway of the proposed Mentone Dam above Prado Dam on the Santa Ana River (Los Angeles District 1975). The probable maximum storm, which was based on a general winter storm, was used as a basis for developing the probable maximum flood for Prado and Mentone Dams. The average depths of precipitation for 6 hr, 12 hr, 24 hr, 48 hr, and 72 hr during the probable maximum storm for the drainage area above Prado Dam were 5.6 in., 10.6 in., 16.5 in., 23.1 in., and 26.3 in., respectively. The distribution of rainfall over each subarea above Prado Dam was determined by taking the ratio of the 10-year, 3-day rain for each subarea to the 10-year, 3-day rain for the entire basin above Prado Dam. The rainfall was distributed over each subarea above Mentone Dam in the same manner.

Santa Ana River Mouth Region

31. At the Santa Ana River mouth in the vicinity of the Pacific Coast Highway there are several interests which should be considered: (a) preservation of the least tern (an endangered species) nesting preserve, including the acquisition of 8 acres on the west side of the channel along the coast, (b) realignment of adjacent storm drain channels necessitated by widening of the Santa Ana River channel, (c) preservation and enhancement of 92 acres of proposed restored marshlands, and (d) disposal of up to 7.5 million cu yd of excavation material which will accumulate from deepening and widening approximately 10 miles of the existing channel. It is anticipated that up to 1,000,000 cu yd of this material is of suitable quality for use as beach nourishment material for adjacent beaches. That portion of the beach being considered for nourishment is shown in Figure 6 during a time of low riverflow (the mouth of the river is completely blocked with littoral material, or longshore drift of sand in the surf zone). Figure 7 shows the river outlet during a time of high riverflow (the sand blockage at the mouth of the river has been flushed away). The sediment-laden freshwater plume also can be seen in this figure. The endangered bird species nesting area and the proposed marsh habitat development area for

Figure 6. Santa Ana River mouth during a time of low riverflow, showing complete sand blockage of the river mouth. This section of coastline (Huntington Beach to Newport Beach) is being considered as the placement location of up to 1.0 million cu yd of material to be excavated during the widening and deepening of the Santa Ana River

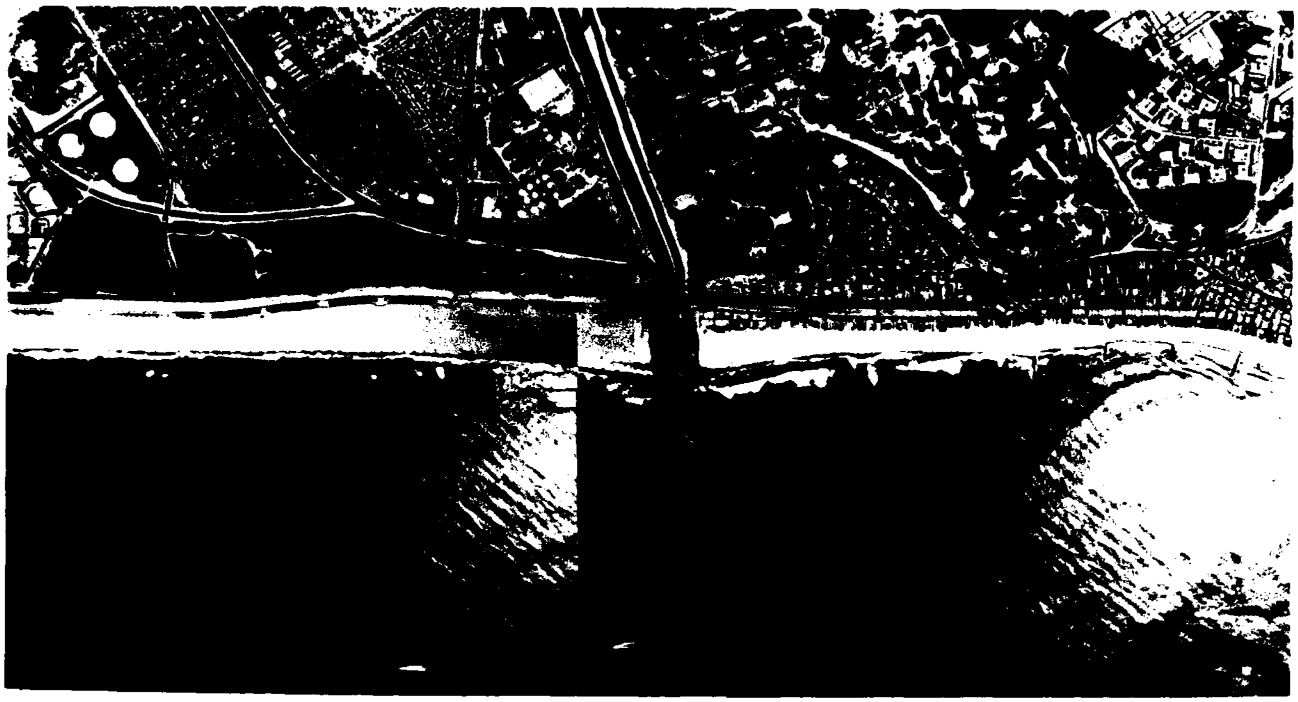

Figure 7. Santa Ana River mouth during a time of high riverflow, showing removal of the sand blockage that accumulates in the river outlet by littoral material during times of low riverflow. Sediment-laden freshwater plume can be seen discharging into the Pacific Ocean

preservation purposes are shown in Figure 8.

32. The 1975 Survey Report's recommended plan called for a larger channel capacity which combines the Santa Ana River channel with the adjacent Greenville-Banning Channel and extends the channel 200 ft eastward. It is proposed to replace this lost area by acquiring an equivalent area or by developing a salt marsh for this purpose. The 1975 recommended plan presently proposes the acquisition of 92 acres (100 acres less 8 acres inside the proposed new channel right-of-way) for estuarine mitigation and preservation. The preservation area development was recommended under the Endangered Species Act which directs all Federal agencies to use their authorities to protect endangered species. Least terns nest in the spring and summer, and it is important to allow their biological patterns to continue uninterrupted. Final plans for the area will be developed through public involvement and coordination with the U. S. Department of the Interior, U. S. Fish and Wildlife Service, California State Fish and Game Department, agencies of Orange County, and the cities of Huntington Beach, Newport Beach, and Costa Mesa.

33. The required degree of flood protection results in an increase in carrying capacity of the flood-control channel, which is reflected in both a deepening and a widening of the present structure. There are, however, serious constraints on the width of the proposed channel. From the Pacific Coast Highway Bridge out to the river mouth (Figure 9) houses exist near the channel on the east side, and 10-ft-diam sewer outfall pipes are buried in the west levee. It is proposed to relocate the Huntington Beach Channel west and adjacent to the least tern nesting area. This provides a minimal but sufficient width channel to carry the design flow of 55,000 cfs in a channel consisting of vertical concrete walls and an earth bottom. The Pacific Coast Highway Bridge will be replaced (exact dimensions of the new bridge will be determined by the California State Department of Transportation). The Santa Ana River flood-control channel and Greenville-Banning Channel will be combined in this region. A plan view and three typical cross sections of this reach of the proposed new project channel are shown in Figures 10-13, respectively.

Figure 8. Santa Ana River mouth, endangered bird nesting area and proposed marsh development area

Figure 9. Santa Ana River (left) and Greenville-Banning Channel (right) during a period of low flow in the river, showing complete blockage of both channels (looking upstream from river mouth to Pacific Coast Highway Bridge)

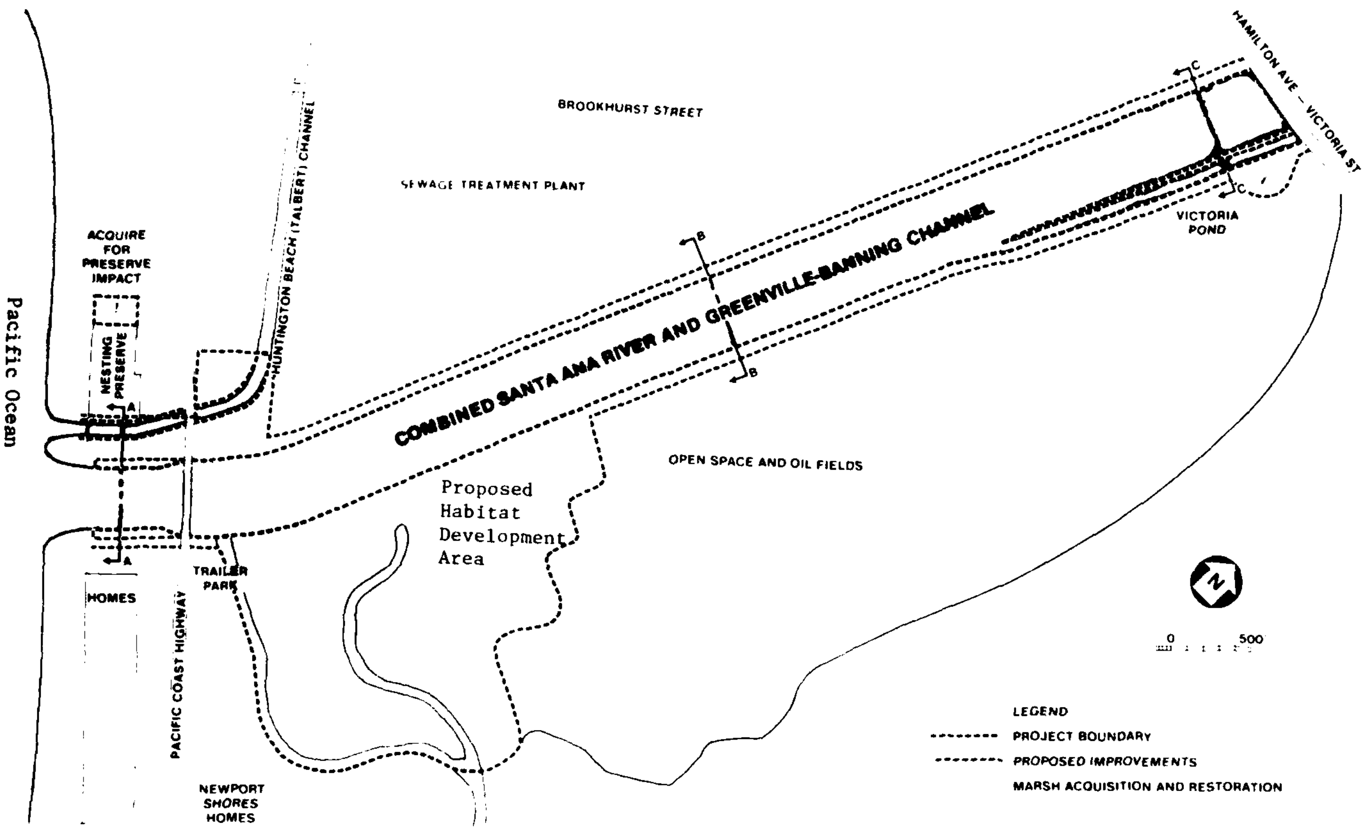

Figure 10. Plan view of proposed combined Santa Ana River and Greenville-Banning Channel, proposed habitat development area and least tern nesting preserve

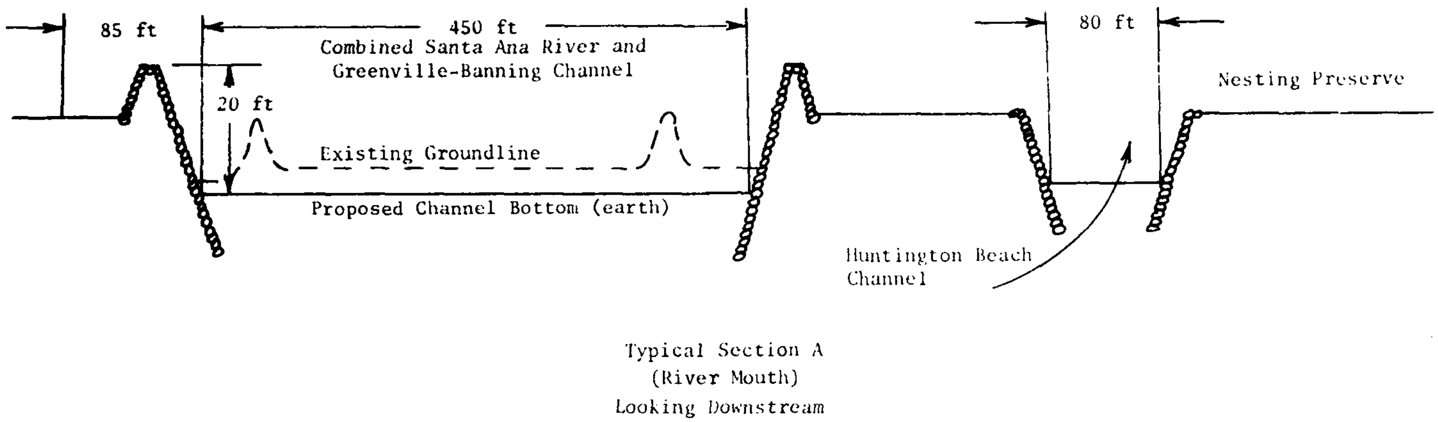

Figure 11. Typical cross section of combined Santa Ana River and Greenville-Banning Channel and Huntington Beach Channel adjacent to least tern nesting preserve

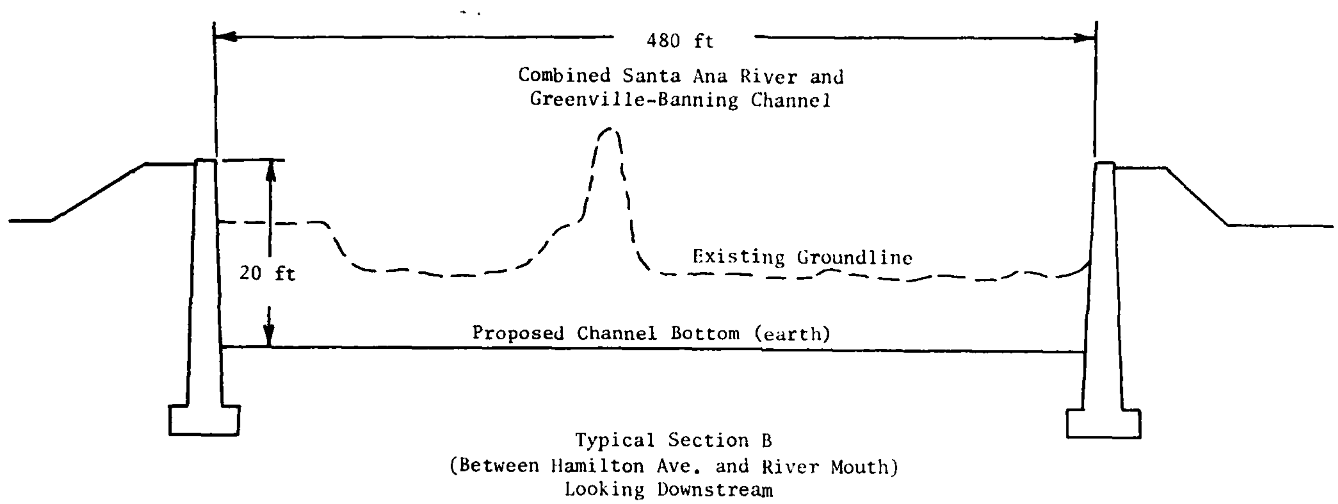

Figure 12. Typical cross section of combined Santa Ana River and Greenville-Banning Channel, between Hamilton Avenue and Pacific Coast Highway

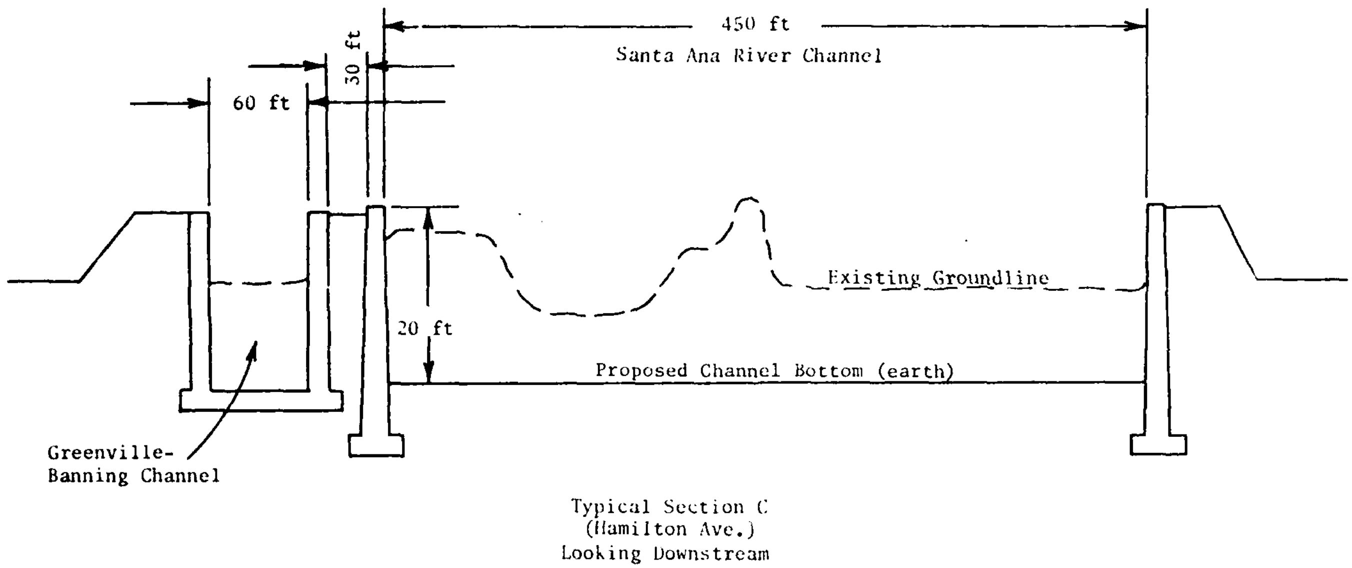

Figure 13. Typical cross section of Greenville-Banning Channel and Santa Ana River channel at Hamilton Avenue

PART IV: LITTORAL PROCESSES, ANAHEIM BAY TO NEWPORT BAY

34. Since the construction of the Anaheim Bay east jetty in 1944, serious erosion of the beaches at Surfside-Sunset Beach has been a continually recurring problem that has necessitated the periodic placement of nourishment material to maintain an acceptable beach for recreation and protection of private and public properties. The average annual rate of erosion in this area (based on placement volumes and topographic surveys) in recent years has been approximately 300,000 cu yd per year (Los Angeles District 1978a). Indications are that the net annual littoral drift is in a southerly direction, and indeed, the beaches along the coast at Huntington Beach appear to be in a relatively stable condition. This is probably due to the fact that the Surfside-Sunset Beach region receives nourishment which serves as feeder material for Huntington Beach before serious erosion has time to occur at Huntington Beach. Farther south, in the vicinity of the Santa Ana River mouth, the beaches are also relatively wide and stable. The existence of the wide beaches in this location, however, can be attributed in large part to the stabilizing jetties that maintain the location of the Huntington Beach, Santa Ana River, and Greenville-Banning Channels. In general, the beach is approximately 600 ft wide immediately north of the Santa Ana River and approximately 400 ft wide immediately south of the river. The reversals in transport direction of the littoral drift provide sufficient material to maintain acceptable beach conditions near the river mouth (Figure 14). Farther south, the beach near Newport Beach has been stabilized with a groin field located immediately to the north of the Newport Submarine Canyon. Otherwise, the apparent southerly net littoral drift would deplete the beaches since the sand would disappear down the canyon and out of the system.

35. The occurrence of erosion (or deposition) along any beach is the result of a number of interrelated factors, including the amount of available beach material, the location of its source, the configuration of the coastline and of the adjoining ocean floor, and the effects of wave, tide, and current action. The existence of a sand beach is the

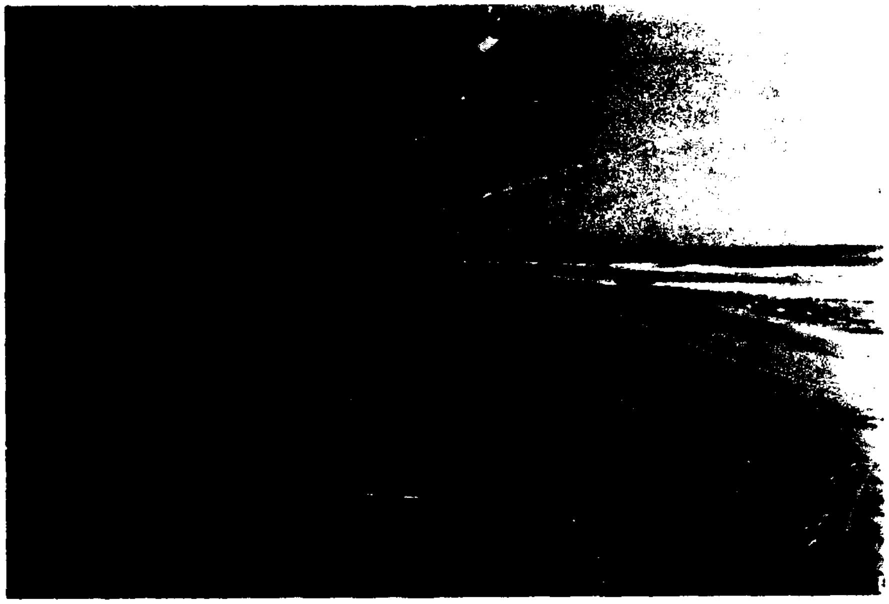

Figure 14. Stable sandy beach immediately south of the Santa Ana River mouth. Beach is approximately 400 ft wide from houses to top of berm line

result of a delicate dynamic balance between a number of these factors, and changes in any of the influential forces tend to perturb the dynamic equilibrium. Knowledge of the fate of the beach sand as it gradually disappears from the beach area is essential to an understanding of the physical processes which interact to stabilize or erode the region. This feeling has been expressed by Moorhouse*:

> ".....I am sure we all agree on the reasons we no longer have river sand being deposited at the various river mouths and concur that there is a need to have flood control projects to protect

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* Vincent G. Moorhouse, Director, Harbors, Beaches, Recreation and Parks, City of Huntington Beach, personal communication to Mr. Tad Nizinski, U. S. Army Engineer District, Los Angeles, 8 January 1979.

the public's health and safety.....Since the ammunition depot was constructed during World War II, we have had numerous sand replenishment programs and subsequent erosion. These programs have been very costly to the public and it appears that we are committed to a very long range sand replenishment project. We have made some attempts to monitor what happens to the sand.....The irony of all these studies is that there is no firm quantitative or qualitative figures which emphatically state what happens to the sand.....Those of us who work on the beach and have lived with this environment for many years firmly believe that we need to seriously investigate a program that definitely establishes where the sand ultimately ends up..... We are looking forward to working with you on the sand tracer study which was commended on 14 December 1978....."

Before permanent solutions to the problem of beach erosion along the coastline from Anaheim Bay to Newport Bay can be developed, and before recommendations can be made regarding the optimum placement of material excavated from the Santa Ana River flood-control project along the beach, it is necessary to have a good understanding of the incipient wave conditions and distribution of longshore wave energy in the region.

Wave Climate

36. Incoming surface gravity waves not only directly affect the operation of marinas and harbors, but also directly contribute to other significant areas of concern such as longshore transport of littoral material in the surf zone and erosion of adjacent shorelines. Wave height, period, direction of travel, frequency of occurrence, and energy of wave groups are characteristics requiring consideration in all of the potentially troublesome areas. In turn, these characteristics are directly influenced by such physical factors as wave exposure, island sheltering, refraction, and shoaling. All these factors interact with the nearshore bathymetry to determine the breaking height and breaking angle of the incoming deepwater waves. It has been shown empirically

by the U. S. Army Engineer Coastal Engineering Research Center (1977) that these characteristics are directly related to the rate of longshore transport of littoral material in the surf zone.

Wave exposure

37. The degree to which a site is open to the directional spectrum of wave energy from distant and local storms is called wave exposure. The amount of wave exposure along the coastline of southern California from Anaheim Bay to Newport Bay is dependent on the configuration of the mainland and the existence of the offshore islands. Complete wave exposure is reduced by the sheltering effects of the California coastline and the offshore Islands of San Clemente, Santa Catalina, San Nicolas, and Santa Barbara. The Los Coronados Islands off the coast of Mexico exhibit a minimal effect, and the Tanner Banks and Cortes Banks probably do not affect the wave transmission to the coast of interest as they lie directly in front of San Clemente and Santa Catalina Islands.

38. Different locations along the coastline are exposed to different wave climates due to the fact that the physical orientation of the coastlines and the islands permit wave exposure windows to vary as one proceeds southward from Point Fermin to Newport Beach. In general, the study area is exposed to open-ocean swell from two different directions. Southern hemisphere swell penetrates the Gulf of Santa Catalina through the southern window which extends from San Clemente Island to the mainland. A very small amount of swell generated in the northern hemisphere also propagates northward through this window, but the overwhelming amount of wave energy which enters this window is southern swell which produces a northward transport of littoral material in the region of interest (Figure 15). The western exposure window between Santa Catalina Island and Point Fermin allows a large amount of northern hemisphere swell to propagate directly down the San Pedro Channel and onto the shores of the study area. According to Emery (1960), the highest waves of the region ordinarily occur in the area between Point Arguello and San Nicolas Island, and these waves are commonly up to 2 metres in height although larger waves up to 6 metres high have occurred with some regularity. The northern hemisphere swell propagating through the

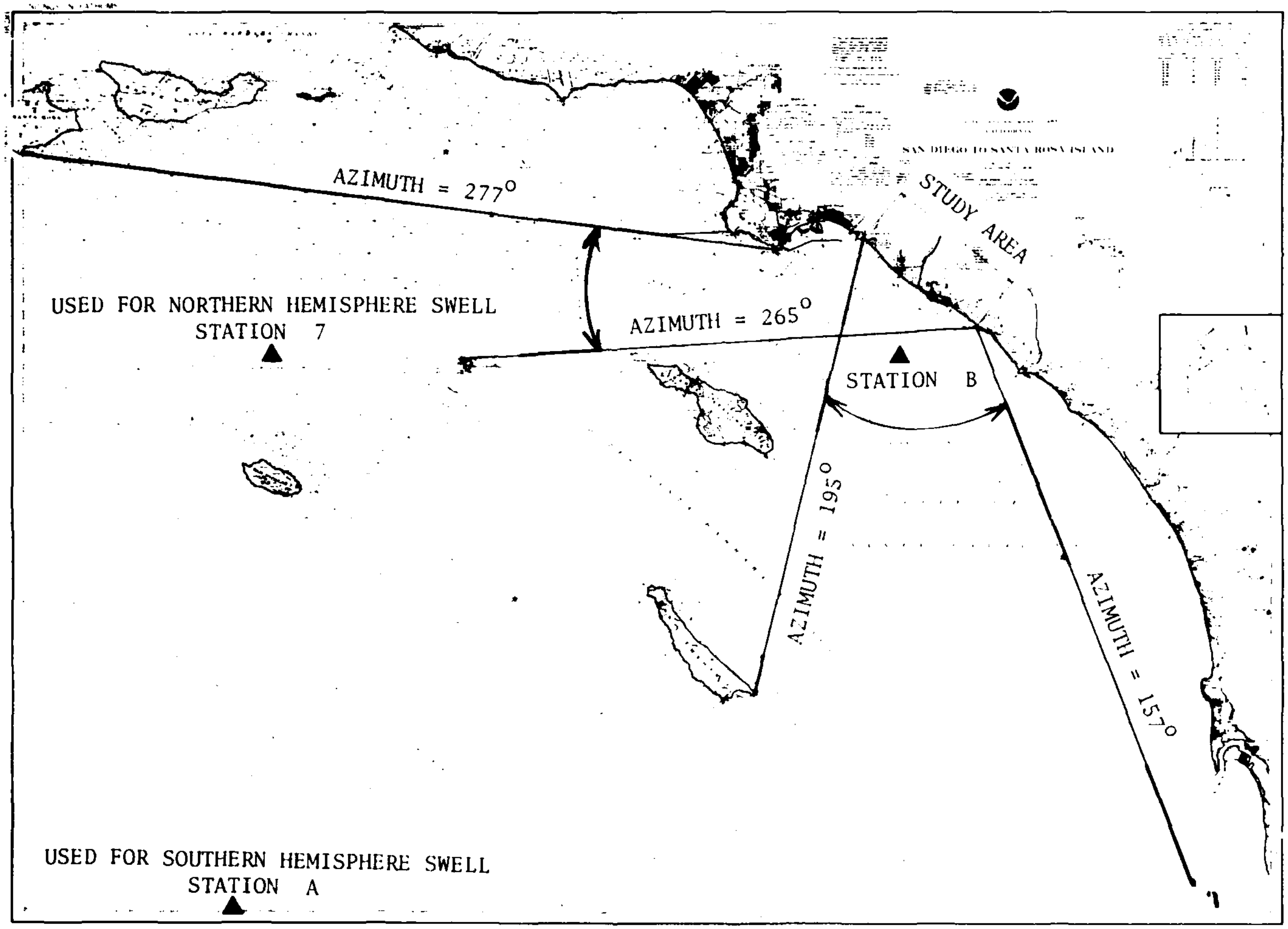


Figure 15. Western and southern wave exposure windows for the study area. Station A was used for southern hemisphere swell, Station 7 was used for northern hemisphere swell, and Station B was used for decayed and local sea waves

western wave exposure window causes a significant amount of southern transport of littoral material along the coast of interest. Local sea breezes also generate shorter period waves (up to 10 sec) from all directions which contribute to both a northward and a southward transport of material.

39. Because the extent of coastline of interest is of considerable length (approximately 17 miles), it is convenient to investigate the littoral transport for three finite sections of this region. Hence, it is imperative that proper consideration be given to the particular point of interest regarding the degree of wave exposure. The northernmost section was selected to extend from the Anaheim Bay east jetty to the Huntington Beach area. The middle section of the coastline of interest was selected to extend from Huntington Beach to the Newport Submarine Canyon. The southernmost section was selected to extend southward from the Newport Submarine Canyon to around Abalone Point. This effectively separated the coastline of interest at natural changes of orientation; hence, a determination of the average wave climate throughout each section could be made for evaluating the incipient wave conditions and the potential longshore transport through each finite section.

40. Potential longshore transport is defined (based on empirical relationships) as the amount of littoral material which a specific wave climate will transport in the presence of an unlimited source (supply) of material. If the source is not unlimited, then the actual longshore transport will be less than the potential transport. When the feeder beach at Surfside-Sunset Beach has been nourished, an essentially unlimited supply of material exists for transport past the downcoast beaches.

Island sheltering effects

41. If the southern California coastline from Anaheim Bay to Newport Bay were not sheltered by the offshore islands, waves would arrive from a wide range of directions even if the direction of the wind in the generating area were relatively constant. According to Arthur (1951), variability of wave direction makes a path of at least 45 deg on each side of the wind. A directional beam pattern of wave intensity

of the form (1 + cos 2θ) has been used to approximate this spreading function. In effect, the intensity is proportional to the square of the wave height, which is consistent with observational data. The result of sheltering, then, is to prevent certain parts of the wave rose from reaching the protected area.

42. In investigating island sheltering, the first consideration is to determine which directions of approach are open to waves of various periods and which are blocked. This cannot be accomplished by simply inspecting the sea level contours of the islands, for shoal water can act as a barrier just as effectively as an island shore. The blocking action depends on both water depth and wave period, with long-period waves requiring deeper water for passage than short-period waves. As a result, any given opening between two islands will present a narrower portal to a long-period wave than it will to a short-period one. With the aid of precise bottom-contour charts, all such avenues of approach were determined for the coastline between Anaheim Bay and Newport Bay. The required integrations were performed by digital computer utilizing a program developed by the Los Angeles District. The precise point selected to ascertain the deepwater wave climate after the effect of sheltering had been evaluated was the midpoint of each section being considered.

43. The island sheltering theory yields not only height-reduction ratios but indicates modification in direction as well. Periods are assumed to remain unchanged. The direction modifications are necessary because, in some cases, sheltering will block out part or all of the primary central portion of the direction sector of a train of approaching waves. When this happens, the wave energy reaching the hindcast point will obviously come from around the two ends of the barrier, and the resulting modified wave train will come from a direction within the original sector but modified toward that end of the barrier around which the larger part of the remaining wave energy came. The island sheltering coefficients, or the percent remaining of the original deepwater wave heights, and the direction-of-approach alterations were applied to the deepwater wave climate being utilized in this analysis. The resulting

sheltered deepwater wave climate was then refracted shoreward to the site of interest. The sheltered deepwater depth in all cases was 600 ft, where the refraction analysis was initiated.

Refraction and shoaling effects

44. The phase speed of a surface gravity wave depends on the depth of water in which the wave propagates. As the wave celerity decreases with depth, the wavelength must also decrease for the period to remain constant. Variation in phase velocity occurs along the crest of a wave moving at an angle to underwater contours because that part of the wave in deeper water is moving faster than that part in shallow water. This variation causes the wave crest to bend toward alignment with the contours. This bending effect, called refraction, depends on the relation of water depth to wavelength. It is analogous to refraction of other types of waves, such as light or sound.

45. As waves propagate from deep water into shallow water, changes other than refraction take place. The assumption generally made is that there is no loss of wave energy and negligible reflection. The power being transmitted by the wave train in water of any depth is equal to the power being transmitted by the wave system in deep water. The wave period remains constant in water of any depth, whereas the wavelength, celerity, and height vary.

46. The transformation of irregular ocean waves is a complex process which is not fully understood. The usual method of treating the problem (which is both practical and relatively successful) is to represent the actual system by a series of sinusoidal waves of different heights, periods, and phases. Such a system now has a two-dimensional energy spectrum. The wave statistics being analyzed in the present study are treated in this manner.

47. Refraction and shoaling effects are important for several reasons. These phenomena determine the wave height in any particular water depth for a given set of incident deepwater wave conditions (i.e., wave height, period, and direction of propagation in deep water). Refraction and shoaling, therefore, have a significant influence on the distribution of wave energy along the coast. The change in wave

direction of different parts of the wave results in convergence or divergence of wave energy, and materially affects the forces exerted by waves on structures and the capacity of waves to transport sand either alongshore or onshore/offshore.

Data sources

48. In recent months questions have arisen regarding the applicability of using a singular wave model for the determination of wave statistics. Most knowledgeable researchers agree that the spectral approach should be significantly better, and indeed, WES is presently engaged in a 5-year project to provide through hindcasting a numerical directional spectral wave climatology for all continental United States coastlines and Hawaii. This wave climatology will ultimately be available to all CE Districts in the form of a computer-based sea-state engineering applications system (SEAS) with the capability to perform nearshore wave transformations such as those necessary for this study. However, initial computations for the coast of California from this new wave study will not be available until the latter part of 1980; hence, it is not possible to delay an investigation of the coastal processes taking place between Anaheim Bay and Newport Bay until this comprehensive data set becomes available. Consequently, the only viable alternative at the present time is to proceed with analyses based upon the best information available.

49. For this particular region of coastline the best available wave data at the present time are believed to be the hindcast wave data of National Marine Consultants (1960) and Marine Advisers (1961). Data stations from these two investigations are located to be more directly representative of the wave climate at the coastal region of interest than those hindcast studies of other investigators. The results and conclusions of this study can be revised and updated, if necessary, as more precise wave data become available. Indeed, some results of the post-construction monitoring program at Surfside-Sunset Beach which was recently initiated can be used to supplement the existing data base. This monitoring program also has established Littoral Environmental Observation (LEO) stations along the coastline from Anaheim Bay to

Newport Bay; however, the data base is quite limited at the present time and cannot be satisfactorily adapted to this particular study.

50. An evaluation of the adequacy of the hindcast data base upon which longshore transport computations are founded would require the establishment of confidence limits during the actual hindcasting procedure. Wave hindcast data in use at the present time have not provided this information because of the inherent limitations involved. Marine Advisers (1961) discussed the fundamental limitations of hindcasting wave data from weather maps. When weather maps are used, two limiting factors are involved. The first concerns the accuracy of the map. Opportunities for error, both human and mechanical, exist at many places in the chain of activities stretching from the weather itself to the symbols on the map. The initial observation may have been correct, depending upon the skill and experience of the observer and the condition of the instrumentation. The second major limitation concerns the subjectivity of weather analyses in general. In considering the oceanic regions of a weather map, the weather forecaster inevitably encounters large areas wherein data are scant or nonexistent. Under these circumstances it is obvious that no two forecasters will produce identical analyses. Such uncertainties can affect a wave hindcast since moderate differences in isobaric spacing can result in significant differences in the wind speeds they imply. The wave hindcasters for Marine Advisers (1961) accepted the work of their meteorological predecessors and on it imposed their own set of subjective interpretations, among which include the size and persistence of fetches, the intensity and direction of winds, and the duration of wind velocities that produce the wave hindcast. Under these limitations, confidence limits for past hindcast efforts really are not available.

51. The southern California coastline from Anaheim Bay to Newport Bay is exposed to deepwater waves propagating from the open ocean from southerly and westerly directions. The offshore islands effectively limit the approach of deepwater waves from other directions. Wave hindcasts have been prepared by Marine Advisers (1961) for three specific locations, one of which (Station A) is located in open water beyond the

sheltering islands (Figure 15). This station is exposed to open-ocean influences from southeast through west to north-northwest, and is considered to be representative of conditions outside the offshore islands. The other two stations are located between the sheltering islands and the mainland. One of these stations (Station B) is positioned approximately 8 miles directly offshore from Newport Beach (Figure 15) and contains information regarding both local sea generation nearshore and decayed sea transferred past the sheltering islands from Station A. National Marine Consultants (1960) Station 7 is located directly west of the beaches of interest and experiences the wave climate propagating onshore between Santa Catalina and Point Fermin. The information of these three hindcast wave data stations is indicative of the wave climate along the shores of interest.

52. Marine Advisers Station A data contain the only information regarding swell waves generated in the southern hemisphere. Accordingly, these data were transferred past the islands by sheltering techniques. Northern hemisphere swell from a southerly direction (which could conceivably be felt by the beaches) was also transferred past the islands from Station A. The northern hemisphere swell from a westerly direction was used directly from Station 7 since this station sensed those waves propagating down the San Pedro Channel. Sea (local sea and decayed sea) was obtained from Station B located inside the sheltering islands directly offshore from Newport Beach.

53. Northern hemisphere swell. The main source of wave energy for southern California waters is northern hemisphere swell originating from winds of Japanese-Aleutian storms that move from west to east across the North Pacific at relatively high latitudes, often stagnating in the Gulf of Alaska. Hawaiian storms that also move from west to east in middle latitudes generally do not produce as large a swell as do the Japanese-Aleutian storms. Tropical hurricane-type storms, which develop off the west coast of Mexico, move in a westerly direction at first and then usually curve to the north and northeast. These occur almost exclusively during the months of July through October. The resulting swell rarely exceeds 6 ft, but a strong storm will occasionally move far enough north

to cause destructively high waves in portions of southern California. Steep pressure gradients around the Pacific high pressure cells can cause strong and persistent north and northwest winds over the extreme eastern Pacific Ocean that result in significant northern hemisphere swell.

54. Southern hemisphere swell. Southern hemisphere swell is generated by winds associated with storms of the austral winter in the South Pacific, storms of even greater size and intensity than those of the northern hemisphere. This swell is most common during August and September (Marine Advisers 1961) but occurs significantly from May through October. The frontal storms of the South Pacific that produce southern hemisphere swell can be classified as either southern storms which move from west to east across relatively high southern latitudes, or New Zealand storms which originate in the general vicinity of New Zealand and move eastward across the middle latitudes. Other types of southern hemisphere storms contribute little or nothing to the swell that affects southern California. The southern hemisphere swell that reaches the area of interest has periods which vary from 12 to 20 sec, but with heights which rarely exceed 4 ft.

55. Sea. Sea is the term applied to short, steep waves which are still in or near the area in which they were generated, as distinguished from swell which refers to longer, flatter waves which have left the generating area and have begun to change their physical characteristics through frequency dispersion. In order to forecast sea, it is necessary to have information of the winds over the water area immediately windward of the forecast location. Wind conditions vary greatly offshore from the southern California coast with a characteristic transformation from relatively mild winds over the inner channels to strong, gusty winds outside the islands. The transition zone extends southeastward from Point Conception in a direction roughly corresponding to the California coastline. Station A lies in the region of strong winds, while Station B definitely is in an area where the winds are usually light. Some of the sea waves outside of the islands are of considerable size and even after having been reduced by decay and island sheltering, their effect on

mainland coasts is not negligible. In order that the statistics resulting from the hindcast efforts should reflect this phenomenon, decay and island sheltering coefficients were applied to the sea information from Marine Advisers Station A and the results were added to the sea information which had been obtained for Station B by applying Sverdrup-Munk-Bretschneider theory to local winds. Hence, the sea statistics of Marine Advisers (1961) are actually a composite of local sea plus decayed sea that has not been sufficiently removed from the generating influences to be called northern hemisphere swell.

Potential Longshore Transport

56. The possible placement of up to 1,000,000 cu yd of suitable material excavated from the Santa Ana River channel enlargement along the coastline necessitates a thorough understanding of the littoral processes in the region. The transport of noncohesive sediments under the simultaneous action of waves and currents takes place along natural beaches and elsewhere when waves become superposed upon currents. The currents may be wave-induced, wind-driven, tidal, stream or river, or may originate from some other mechanism.

57. Because of refraction, waves usually break at a fairly small angle to the beach. The mass of water piling up in the surf zone generates a wave-induced current that flows along the beach and is known as the longshore or littoral current. This longshore current, though relatively mild, is capable of transporting vast quantities of sediments that are tossed into suspension by the turbulence associated with wave breaking. In addition, the water mass produced by the breaking process rushes up the beach face at a slight angle, and then down the beach face in such a manner that there is a zigzag path to the particles of water on the beach. Sand particles traverse the same sort of pattern along the beach face (Johnson and Eagleson 1966). Hence, the total longshore drift of sand consists of the general drift due to the longshore current in the breaker zone and the zigzag path on the foreshore due to wave uprush and backwash (or runup and rundown).

58. Longshore currents flow parallel to shore, accumulating in volume as more mass is introduced by additional breaking waves until regions of return flow through the breaker zone are created (either rip currents or underflow return currents). Longshore currents typically have mean values of about 1 fps; observed speeds of 3 fps are quite unusual. Although low in magnitude, longshore currents are quite significant in beach processes because they flow along the shore for extended periods of time. The longshore current velocity appears to be quite sensitive to breaker angle a_b* (which the wave crests make with the shoreline) and somewhat sensitive to breaker height H_b. An estimation of the magnitude of a longshore current may be obtained from the modified Longuet-Higgins (1970) expression:

$$V_{1s} = 20.7m(gH_b)^{1/2} \sin 2a_b \tag{1}$$

where

V_{1s} = velocity of the longshore current
m = beach slope
g = gravitational constant

59. Most investigators have attempted a correlation between wave characteristics and measured longshore transport rates. Intuitively, the rate at which a transport process takes place should be related to the total power available for transporting material. Accordingly, the procedure which has evolved is to determine the alongshore component of wave power, or energy flux, in the surf zone. The alongshore energy flux is approximated under the assumptions of conservation of energy in shoaling waves and application of Airy wave theory. Based on these assumptions, the energy flux at the breaker zone is:

$$P_{1s} = [(\rho g)/16](H_b^2 C_g \sin 2a_b) \tag{2}$$

* For convenience, symbols and unusual abbreviations are listed in the Notation (Appendix K).

where

P_{ls} = alongshore component of wave energy flux per unit length of beach

C_g = group velocity or the velocity of propagation of wave energy

C_g = C, the wave celerity in shallow water

If the energy density at breaking can be approximated by linear theory:

$$E = H_b^2 \qquad (3)$$

and if the wave speed at breaking can be approximated by solitary theory:

$$C_g = C \simeq (2\ gH_b)^{1/2} \qquad (4)$$

Equation 2 can now be expressed in terms of the wave breaking characteristics of breaker height H_b and breaker angle a_b as:

$$P_{ls} = 32.1H_b^{5/2} \sin 2a_b \qquad (5)$$

following the development of CERC (1977).

60. A number of empirical equations have been advanced since the early 1950's that relate the longshore component of wave energy flux, Equation 5, with measured values of volumetric longshore transport. The relationship developed by CERC, based entirely on 23 field observations and no laboratory data, is:

$$Q_{ls} = 7{,}500P_{ls} \qquad (6)$$

where

Q_{ls} = longshore transport in cubic yards per year

The coefficient, 7,500, in Equation 6 is about 83 percent larger than the corresponding coefficient that appeared in an earlier edition, because the earlier correlation was based on fewer field observations

and on a tremendous number of laboratory observations. It was determined that the small-scale laboratory data completely overwhelmed the small number of field observations; hence, it was deemed desirable to eliminate laboratory results and supplement the existing field data with more recent prototype observations. Equation 6 is displayed graphically in Figure 16 which also shows the field data giving rise to the expression.

61. In order to apply Equations 5 and 6, the breaker height, H_b , and the breaker angle, a_b , must be known for each element comprising the deepwater wave statistics matrix. The breaker height depends directly on the deepwater wave height and deepwater wave period, as also does the breaker angle. These breaker values of height and angle are determined by a refraction analysis. Since it would be virtually impossible from both a time and cost standpoint to perform refraction computations for each element in the deepwater statistical tables, the procedure adopted was to develop calibration curves of breaker height and breaker angle by performing refraction computations of selected values of deepwater height and period, for those directions-of-approach tabulated in the hindcast wave climate. Longshore transport computations were performed for the three finite sections of southern California between Anaheim Bay and Abalone Point, previously discussed, by applying refraction analyses to the latest hydrographic survey data which was overlain by a 600-ft-square depth grid over an area 14.3 miles x 30.0 miles. The 30.0-mile direction is alongshore and the grid penetrated into the ocean approximately 14.3 miles. This grid size provided adequate detail and permitted the computations to proceed to the breaker zone for all wave conditions. From these calibration curves of the effect of deepwater wave height, deepwater wave period, and direction-of-approach on breaker height (Appendixes A, B, and C for Surfside-Sunset Beach region, Santa Ana River mouth region, and Newport Beach region, respectively), and of these same effects on breaker angle (Appendixes D, E, and F for Surfside-Sunset Beach region, Santa Ana River mouth region, and Newport Beach region, respectively), the appropriate value for each element appearing in the wave statistics matrix could be determined. Ultimately, the amount of potential longshore transport attributed to that element was

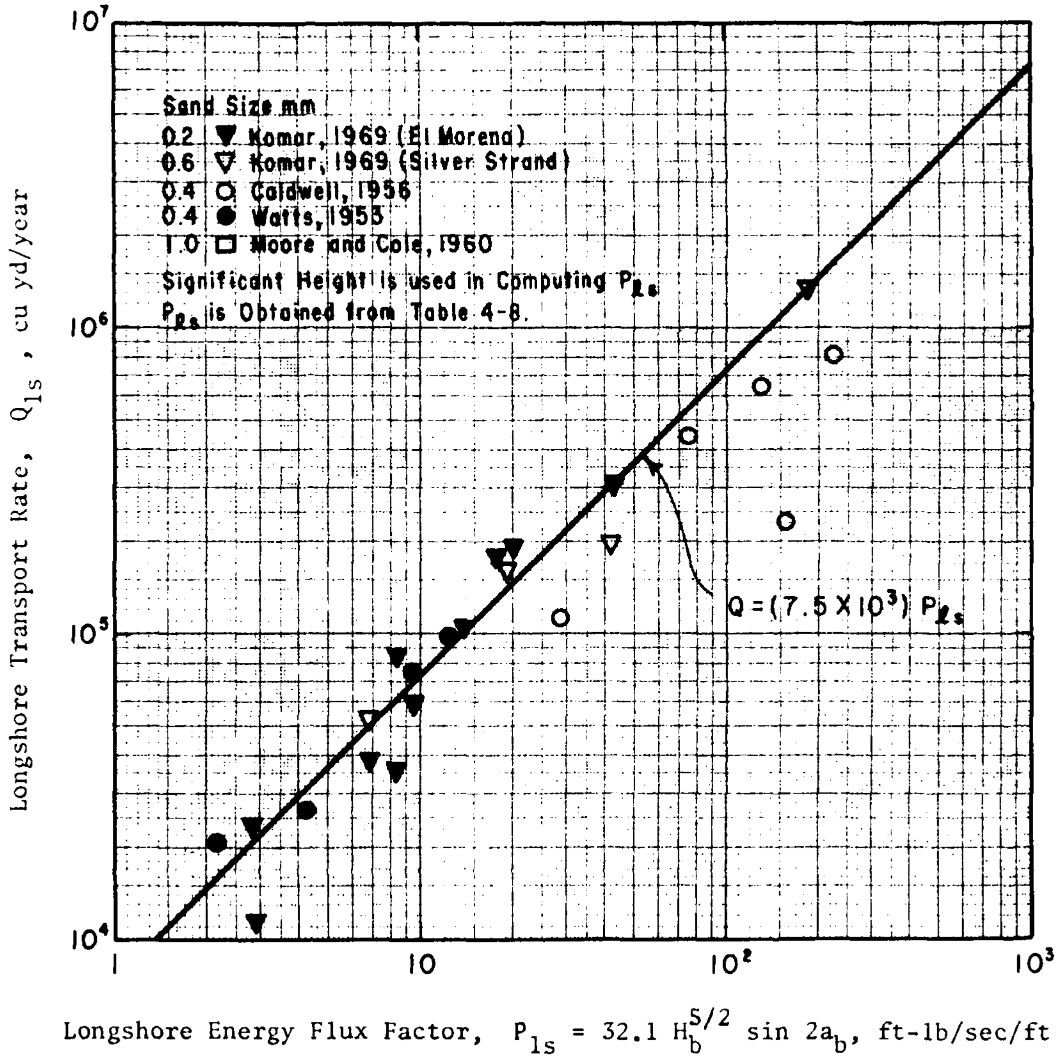


Figure 16. Prototype field data for development of longshore transport relationship (after CERC 1977)

computed. The breaker height H_b and breaker angle a_b for each element appearing in the wave statistics tables are determined by entering the graphs of Appendixes A-F with the appropriate deepwater wave

height H_o , and reading the corresponding value of H_b and a_b from the appropriate wave period T curve.

62. Typical examples of the effects of refraction on wave characteristics are shown in Figure 17 for an 18-sec wave approaching from the south and in Figure 18 for an 18-sec wave approaching from the west. These are the two dominant directions-of-approach for this entire section of coastline, and the bathymetry causes significant convergence and divergence of wave energy at various locations. The complex combination of beach orientation and wave energy divergence or convergence tends to obscure an apparent indication of whether the material transport rate will decrease or increase. Only after a complete analysis of the data is an understanding of the phenomena possible.

63. The frequencies-of-occurrence (annually) of open-ocean deepwater swell (southern and northern hemispheres) are presented in Appendix G. When these waves have propagated shoreward past the sheltering islands and have been accordingly altered in both direction and amplitude, although still in deep water, the accumulation of these sheltered frequencies will still be influenced by nearshore bathymetric variations. Ultimately breaking will occur, and the magnitude of the breaker height and the angle of breaking with the beach are important parameters in evaluating potential longshore transport of littoral material. The individual matrix element computations are shown in Appendixes H, I, and J for Surfside-Sunset Beach region, Santa Ana River mouth region, and Newport Beach region, respectively.

64. Summaries of the potential longshore transport computations for these three regions are presented in Tables 2-4, respectively. These tables are arranged to display the influence of sea, southern swell, and northern swell on the overall net and gross transport on a monthly basis. Since the same deepwater wave statistics were applied to all three locations, the differences in the transport rates and quantities are directly attributable to differences in open-ocean wave exposure, localized bathymetry near the sites, and the general differences in orientation of the shoreline at the three locations.

65. The computations at all three locations indicate a net

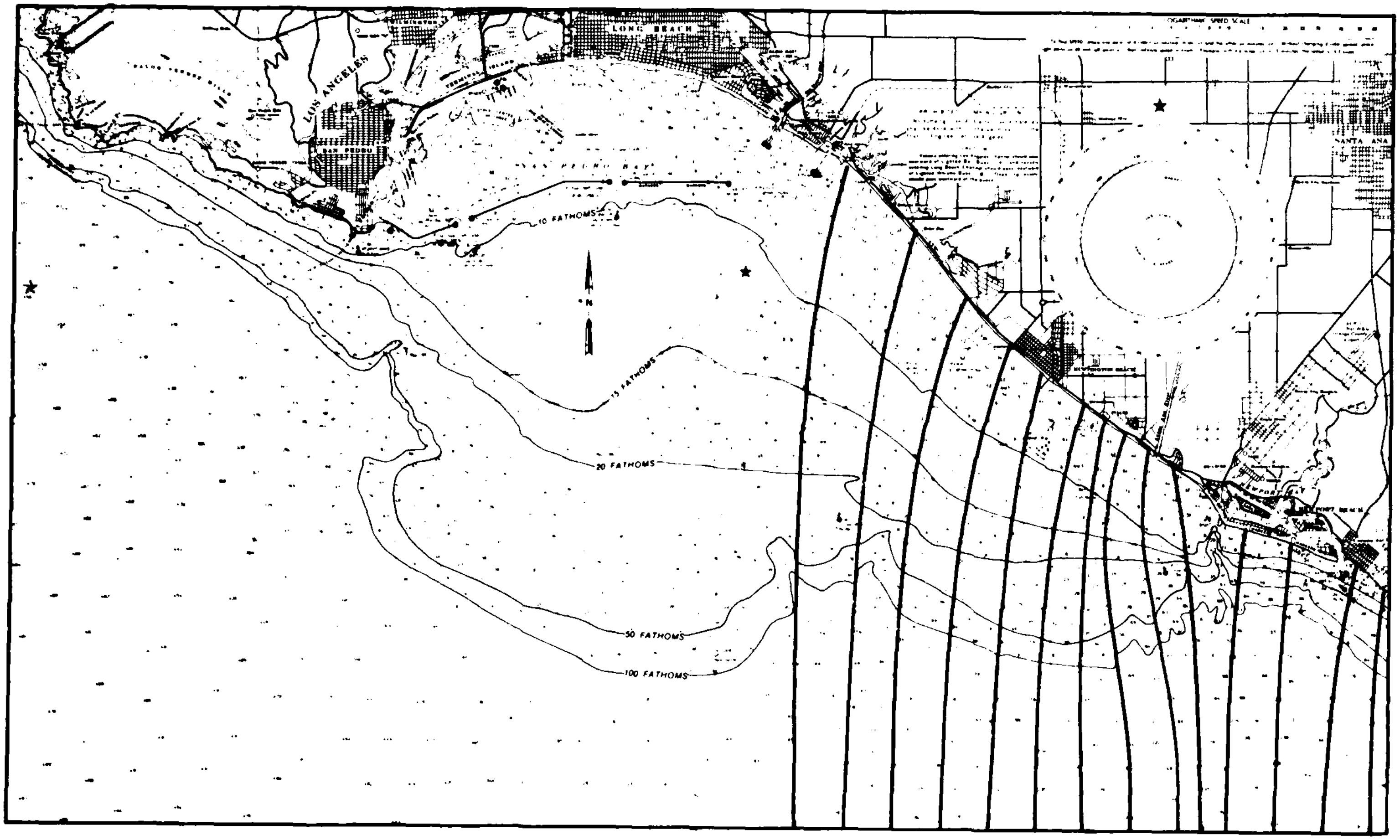


Figure 17. Effects of offshore bathymetry on refraction of 18-sec sheltered deepwater wave propagating from the south

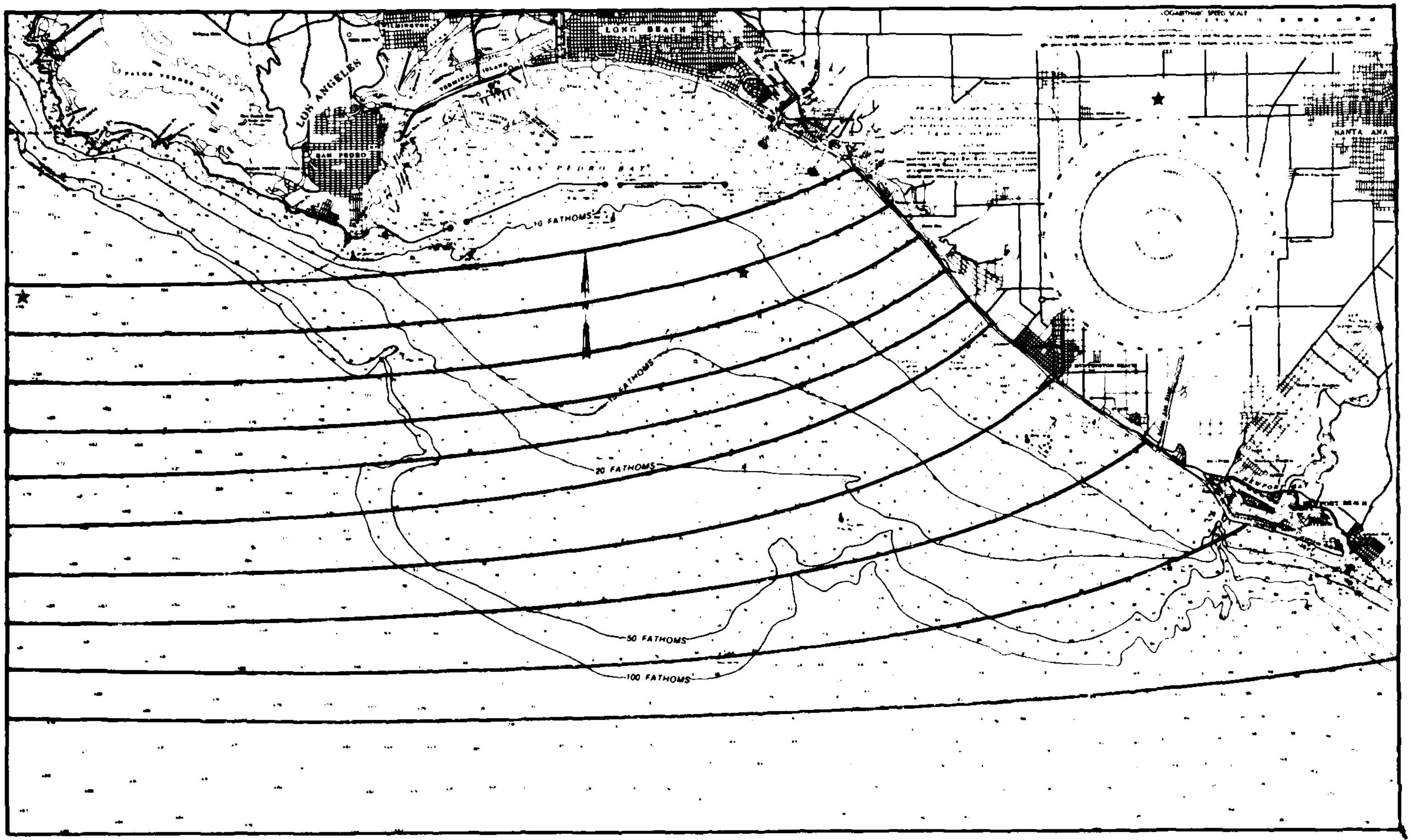


Figure 18. Effects of offshore bathymetry on refraction of 18-sec deepwater wave propagating from the open ocean from the west

southerly transport which is in qualitative agreement with other similar investigations, for example, Emery (1960), Herron and Harris (1962), Inman and Frautschy (1965), and Shepard and Wanless (1971). The gross transport rates are also the same order of magnitude as previously reported. While the net southerly transport rate at Surfside-Sunset Beach appears somewhat less than the average amount of beach nourishment material which is known to have historically been placed on the beach, this disparity is due in part to material being transported out of the system into the Anaheim Bay entrance channel. Based only on dredging records of the Anaheim Bay entrance channel, this material cannot be precisely accounted for as other deposits take place in the channel from Anaheim Bay proper. The fact that more material is being transported into the Huntington Beach region than is being transported out of this region assures the maintenance of the status quo at this location as long as beach nourishment takes place along the feeder beach.

66. The gross and net annual potential longshore transport computations are shown in Figures 19 and 20, respectively, and from these displays it is apparent that the wave climate and bathymetry combine to provide for a significant nonlinearity in the volume of material transported with distance from the Anaheim Bay east jetty by all three methods of wave transport (sea, northern swell, and southern swell). This can be partially attributed to the vast shoal region in front of San Pedro Bay and Surfside-Sunset Beach, as contrasted with the penetration of the Newport Submarine Canyon almost to the surf zone farther downcoast. Previous studies by WES (Hales 1978) of littoral processes in the Oceanside, California, region where the offshore contours are more uniform and more nearly parallel with the coastline indicated a fairly uniform increase in transport rates with distance away from the beginning of the littoral cell. Because of the periodic beach nourishment activities in the Surfside-Sunset Beach region (as the need arises), essentially an unlimited amount of material is available for littoral transport. Since this is even more correct farther downcoast, the potential longshore transport computations (which are strictly applicable only to a region where an unlimited source of transportable material exists) fairly well

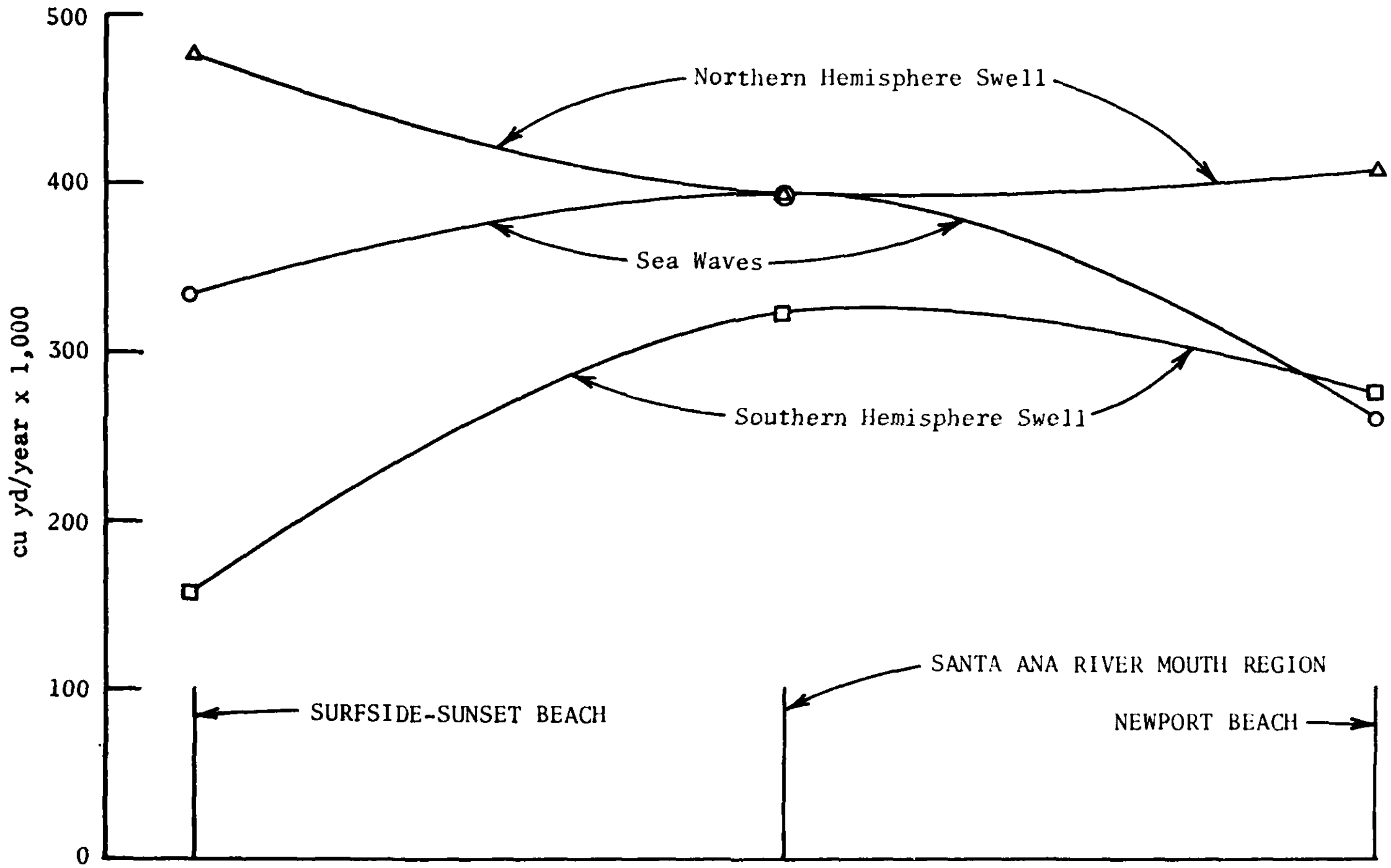


Figure 19. Gross annual potential longshore transport from Surfside-Sunset Beach to Newport Beach

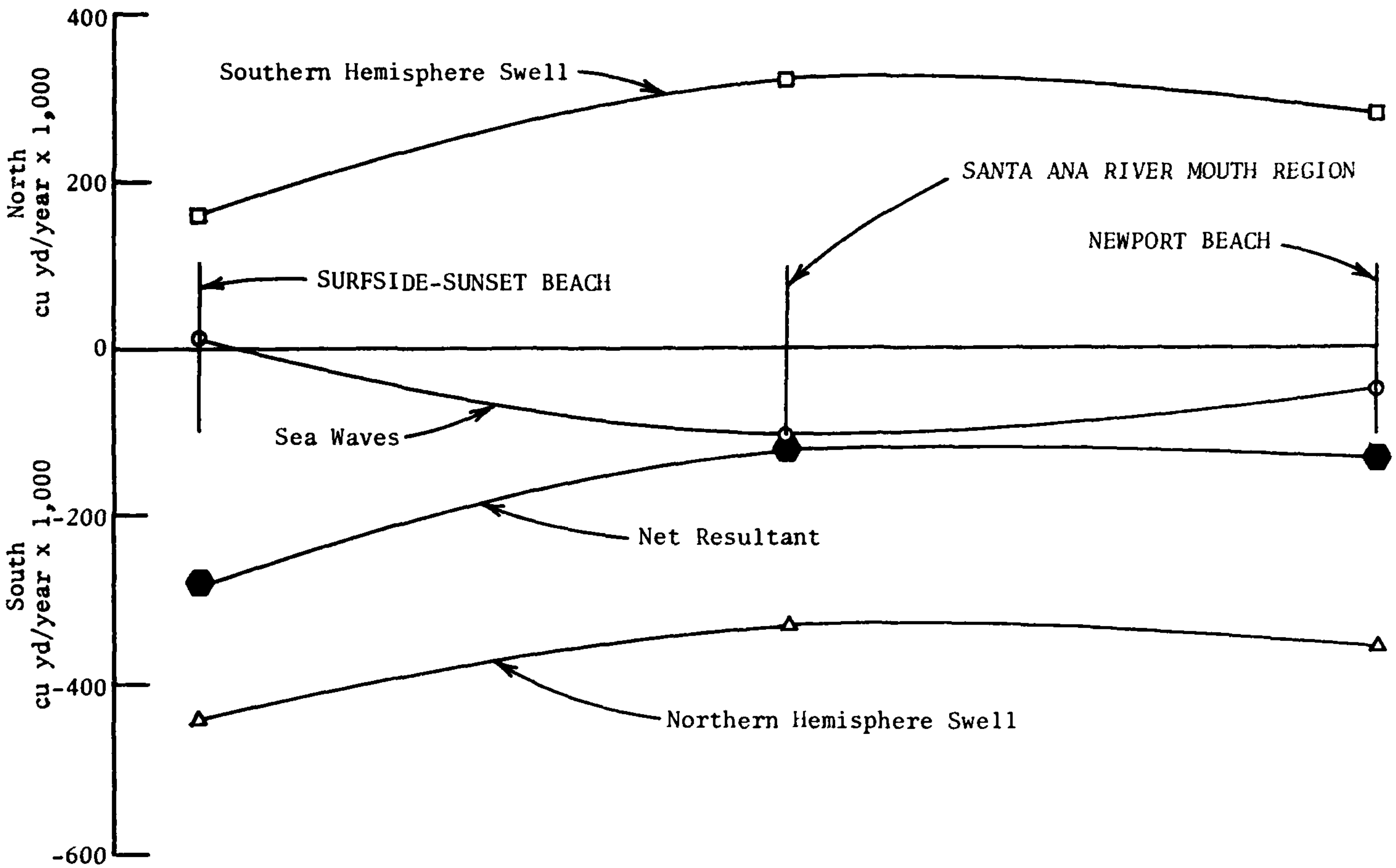


Figure 20. Net annual potential longshore transport from Surfside-Sunset Beach to Newport Beach

approach the actual transport processes in the vicinity.

67. In order for potential longshore transport computations to provide useful information for the design and deployment of sand bypassing systems at harbor entrances, beach erosion studies, beach nourishment investigations, or for other temporal phenomena insight, it is necessary that seasonal or monthly transport rates be determined. Accordingly, the annual quantities were decomposed into the components occurring, on the average, on a monthly basis. The total monthly potential longshore transport quantities are shown in Figure 21 where it can be observed that a significant amount of material moves both north and south each month of the year at all three regions of interest, although there is practically no northern transport in April and November and only relatively minimal southern transport from June to November. The winter and early spring months of January, February, March, and April (particularly February) exhibit the greatest amount of potential longshore transport.

68. The gross monthly potential longshore transport rates are shown in Figure 22 where the results of the complex interaction of beach orientation and island sheltering effects can be observed in the variation of transport capacity at the various locations. The Surfside-Sunset Beach area is more shielded from the effects of northward transport by southern hemisphere swell during the summer months than are the other two regions. Consequently, this area is more exposed to the southward transport of material by northern hemisphere swell than are the other locations. It is interesting to note that the Santa Ana River mouth region experiences a significant amount of gross transport during the summer months of July through October, which is also a time of low (or no) flow of water down the Santa Ana River. Hence, the capability of the river to flush littoral material from the river mouth is minimal. The conclusion is that, if tidal exchange is required through the river mouth, then some kind of operational and/or structural measures must be developed to ensure this capability. During the winter months when even more potential longshore transport is occurring, the river discharge may tend to provide an open river mouth.

69. On a net basis, the Santa Ana River mouth region experiences

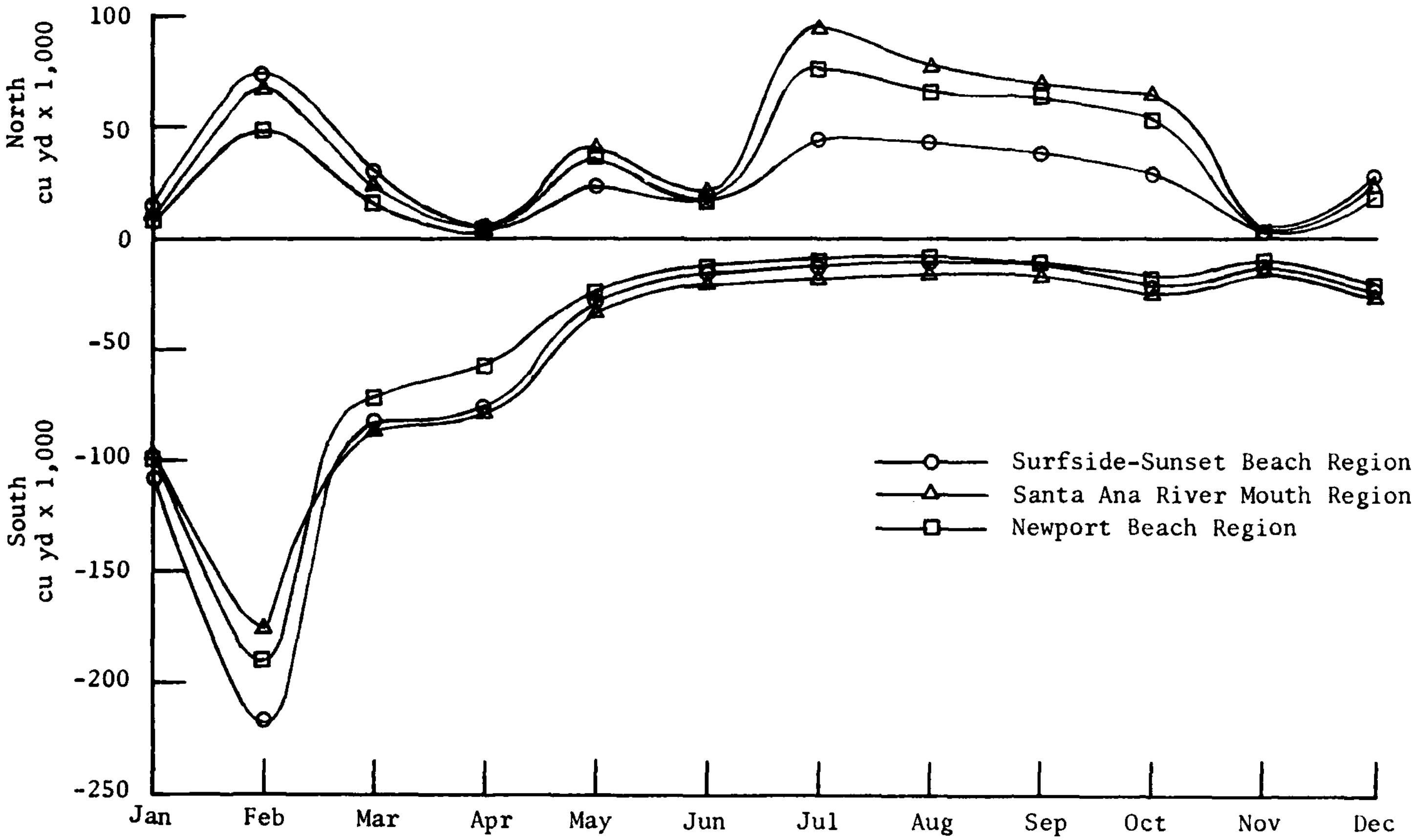


Figure 21. Monthly potential longshore transport from Surfside-Sunset Beach to Newport Beach

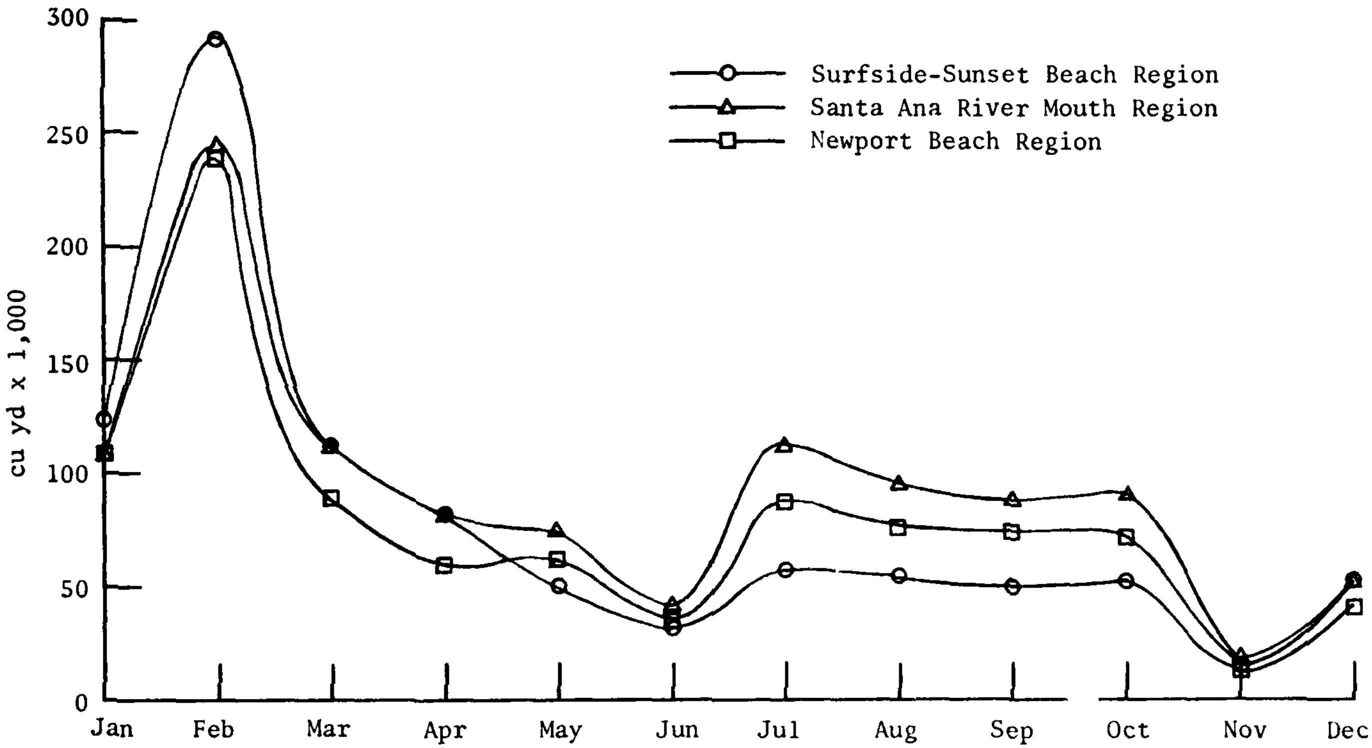


Figure 22. Gross monthly potential longshore transport from Surfside-Sunset Beach to Newport Beach

less southerly transport than either of the other two regions (Figure 23). This figure is a display of the net monthly potential longshore transport rates and shows that there is, in general, a gradual drift of material to the south in the winter months of January through April, and a gradual drift of material to the north during the summer months of July through October, with the overall net drift being to the south. Essentially no net movement of material is occurring from May to June and from November to December along any reach of the coastline of southern California from Anaheim Bay to Newport Bay. June and November are also the months of the least gross movement of material along this entire section of coastline.

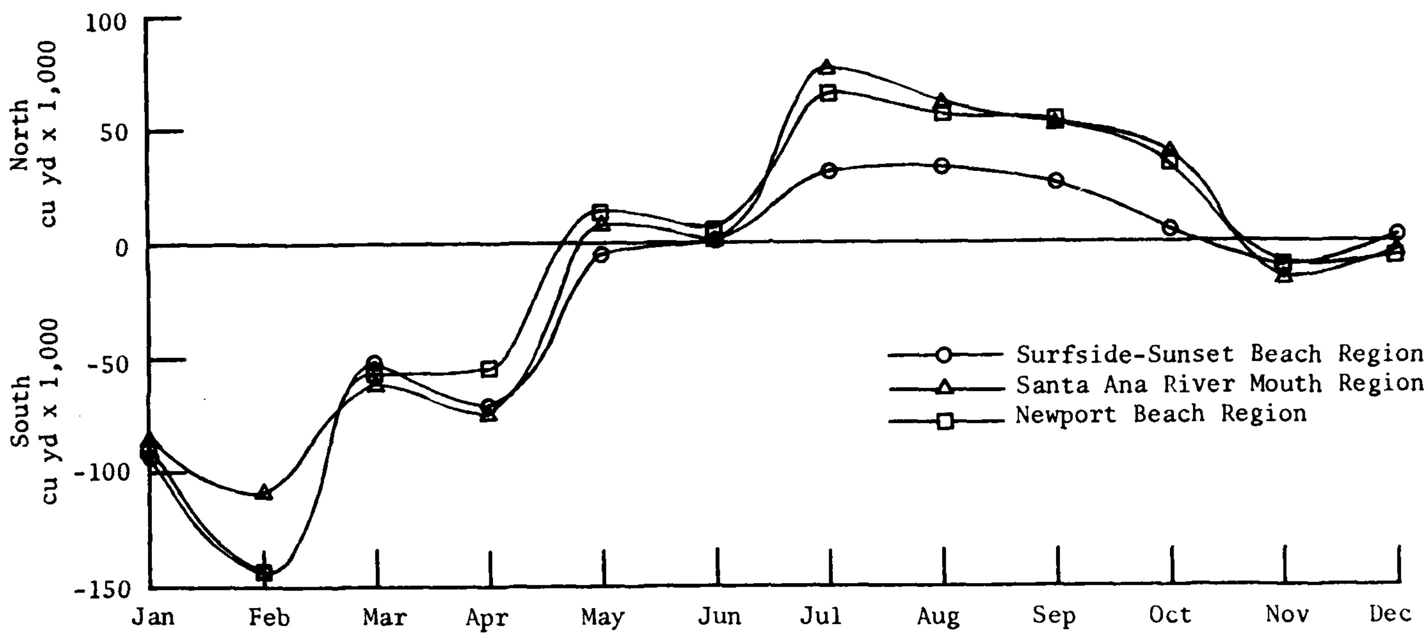


Figure 23. Net monthly potential longshore transport from Surfside-Sunset Beach to Newport Beach

PART V: SANTA ANA RIVER MARSH HABITAT DEVELOPMENT

70. The 1975 Survey Report's recommended plan for increasing the width of the lower reaches of the Santa Ana River for effective flood-control purposes will alter the habitat or feeding area of the California least tern. This alteration can be offset by acquiring an equivalent area or by developing a salt marsh for this purpose. The plan proposed at present recommends for estuarine habitat development and preservation the acquisition of 84 acres lying immediately east of the Santa Ana River and immediately north of the Pacific Coast Highway, adjacent to the Newport Shores Marina. While it appears technically feasible to construct the restored marsh to any desired topography, concern has arisen about the hydraulic design of the interface system which transmits the tidal prism into and out of the marsh. Another closely aligned area of concern is the maintenance of an opening at the mouth of the Santa Ana River to permit tidal exchange with the marsh habitat region.

Newport Shores Marina Water Quality

71. The deterioration of water quality in the Newport Shores Marina was investigated by Roberts (1971), and it was determined that several factors had contributed to the situation in the marina and to the poor water quality conditions in Greenville-Banning Channel as well. The summer sand blockage of the mouth of the Greenville-Banning Channel resulted in a very small tidal area. This curtailment of tidal action in the channel reduced the possibility of summer tidal exchange through the tide gate into the marina to almost negligible proportions. New housing and commercial development in the channel drainage area had measurably increased the inflow of surface-drainage pollutants which were not being flushed directly out to the ocean but remained for some time in the lower reaches of the channel because of the sand blockage.

72. Moffatt and Nichol (1973) performed engineering feasibility studies of methods for maintaining continuity with the ocean to permit tidal exchanges through the Greenville-Banning Channel to the marina.

It was determined that the sand blockage at the mouth of the channel was due to insufficient tidal exchange and insufficient streamflow during dry weather to maintain an opening against the beach-building capacity of the long summer ocean waves. The exchange between Greenville-Banning Channel and Newport Shores Marina was further restricted by a 5-ft-diam gated culvert with its invert set at -2.9 ft msl. This gate was installed to prevent high-water levels in the flood channel from inundating the low-lying developed areas of Newport Shores, but was intended to be closed only when fluvial flooding appeared imminent. However, the gate has been left closed much of the time in order to maintain a high-water level in the marina channel. Moffatt and Nichol (1973) recommended five possible solutions to the sand blockage problem.

Plan 1, major tidal prism increase

73. O'Brien (1931) established a relationship between the cross-sectional area of an inlet and its tidal prism. The relationship, based primarily on data pertaining to Pacific coast inlets, was:

$$A = 4.69 \times 10^{-4} P^{0.85} \qquad (7)$$

where

A = minimum cross section of the entrance channel measured below msl, sq ft

P = tidal prism corresponding to the diurnal tide, cu ft

O'Brien (1969) later reviewed this relationship in light of more recent data that had become available since the initial study. Included in this review were data for 28 inlets (9 on the Atlantic coast, 18 on the Pacific coast, and 1 on the Gulf coast). O'Brien concluded from this review that the original relationship agreed closely with the contemporary data for inlets with two jetties but that inlets without jetties appeared to be better represented by the linear relationship:

$$A = 2.0 \times 10^{-5} P \qquad (8)$$

74. Moffatt and Nichol (1973) determined that the

Greenville-Banning Channel had a potential tidal prism of about 40 acre-feet, and the Newport Shores Marina (with the tide gate open) had a prism of about 20 acre-feet. In order to be reasonably sure that the outlet would remain open, it was believed the tidal prism should be increased to around 1,000 acre-feet. This could be accomplished by excavating a tidal lagoon of about 180 acres to about -3 ft msl in the oil field (the presently proposed marsh habitat development area), with an outlet about 200 ft wide into the Greenville-Banning Channel. The plan would have required the construction of protective dikes around the housing developments which probably would not have been acceptable (Moffatt and Nichol 1973).

Plan 2, minor tidal prism increase

75. This plan recommended deepening the Greenville-Banning Channel, deepening and widening the Newport Shores Channel, and replacing the tide gate with a 20-ft-wide bridge or box culvert. This plan was reasonably expected to maintain the Greenville-Banning Channel outlet during the summer.

Plan 3, outlet modification

76. Because the Huntington Beach Channel maintains an open outlet at all times, it was proposed to divert the Greenville-Banning Channel across the Santa Ana River channel into the Huntington Beach Channel just south of the Pacific Coast Highway. The diversion dike and channel would require a small amount of annual maintenance, but this would assure tidal exchanges between the Greenville-Banning Channel and Newport Shores Marina.

Plan 4, groin plus mechanical maintenance

77. It was suggested that the sand drift into the Greenville-Banning Channel during summer months could be reduced by means of a removable groin in the extension of the east jetty and the Greenville-Banning Channel could be maintained with mechanical equipment. This plan relied entirely on the effectiveness of the removable groin in keeping sand away from the entrance during the summer months.

Plan 5, well water for Newport Shores Channel

78. The final plan proposed to provide extraction wells at critical

points in the Newport Shores Channel area and induce channel flow toward the tidal gate and exchange aerated well water for tide water in the Newport Shores Channel.

Rejected plans

79. Buried pipeline. Moffatt and Nichol (1973) considered several other plans that were summarily rejected. One of these plans called for a large buried pipe extending from the east end of the Newport Shores Channel under the Pacific Coast Highway and out to a submerged outlet in the ocean. Its purpose would be to obtain a tidal exchange that would be completely independent of the Greenville-Banning outlet and the tide gate. The cost of installing a pipe large enough to provide sufficient exchange water to be effective (at least 10 ft in diameter) would be prohibitive. The problem area might simply be transferred from the east to the west end of the Newport Shores Channel. The desired high level of water in the channel could not be maintained indefinitely. Unless the ocean outlet could be made very deep and carried well offshore, it would be a hazard to swimmers. Numerous problems would arise in obtaining the necessary easements and permits to install the pipe.

80. Operation of existing tide gate. This plan relied solely on the operation of the existing tide gate to maintain water quality in Newport Shores Channel and the lower end of the Greenville-Banning Cnannel. The full effectiveness of the Newport Shores tidal prism would be restored by deepening about 2,000 ft of shoal channel to slightly below the tide gate invert elevation. After unblocking the Greenville-Banning Channel by mechanical means, the opening would be maintained by timed releases of water through the tide gate. Further analysis indicated that the surge of water released from the gate would be largely dissipated by backflow up the Greenville-Banning Channel.

Marsh Habitat Requirements*

81. Tidal marsh development on the proposed site which was former

* This section extracted from an unnumbered report by C. J. Newling, "Feasibility Report on a Santa Ana River Marsh Restoration and Habitat Development Project," 1979.

Santa Ana River floodplain appears technically feasible. The critical element in tidal marsh development is that the final surface elevations must lie within the intertidal zone. The normal higher high tides at the proposed site are on the order of +3.3 ft mllw, while approximately 80 percent to 90 percent of the surface of the site is above that elevation. High tidal marsh still persists on the site, however, and is characterized by plant species which include pickleweed (Salicornia virginica), shore grass (Monanthochloe littoralis), and alkali heath (Frankenia grandifolia). Restoration of the Santa Ana River marsh will require removal of surface material to lower elevations within ranges of tidal inundation compatible for growth of these and other marsh plants. Also included will be habitat development for the California least tern (Sterna albifrons browni), Belding's savannah sparrow (Passerculus sandwichensis beldingi), the light-footed clapper rail (Rallus longirostrus levipes), and possibly other rare species.

Projected revegetation of the site

82. California salt marshes are usually characterized by Pacific cordgrass (Spartina foliosa) in the low marsh and pickleweed in the high marsh. Pacific cordgrass is a salt marsh grass that ranges southward with patchy distribution along the Pacific coast of North America from Humboldt Bay. Less is known about it than other species of Spartina. It does, however, grow in the lower and middle portions of the littoral zone of Pacific coast tidal marshes where the salinity is less than 35 parts per thousand. Generally, the lower and upper limits of its inundation tolerance levels are at 50 percent and 76 percent of the local tidal range, respectively. At the Santa Ana River site, Pacific cordgrass will probably survive between el 1.2 ft and 3.3 ft mllw with its heaviest growth between el 1.4 ft and 2.4 ft mllw. Here frequency of tidal inundation will most likely eliminate growth by other less-tolerant species. Above el 2.4 ft mllw, pickleweed as well as other more salt-tolerant species will become dominant, while Pacific cordgrass will become less common due to its low tolerance for the higher salinity which is common to California high marshes. Pickleweed is a widespread species exhibiting a broad range of tolerance within and above the intertidal

zone, and can withstand extremely saline conditions. Its heaviest growth usually occurs within the upper littoral zone and into the maritime zone. At the Santa Ana River marsh site, heavy pickleweed growth will probably occur from el 2.4 ft to and above 4.0 ft mllw, depending on soil moisture and salinity. An example of a natural west coast tidal marsh, the desired product at the Santa Ana River site, is shown in Figure 24, while an example of an artificially created marsh habitat development area is shown in Figure 25. California cordgrass and pickleweed dominate both the natural and the artificial habitats. Closeup views of these two marsh plants are shown in Figures 26a and 26b, respectively.

Projected animal use of the site

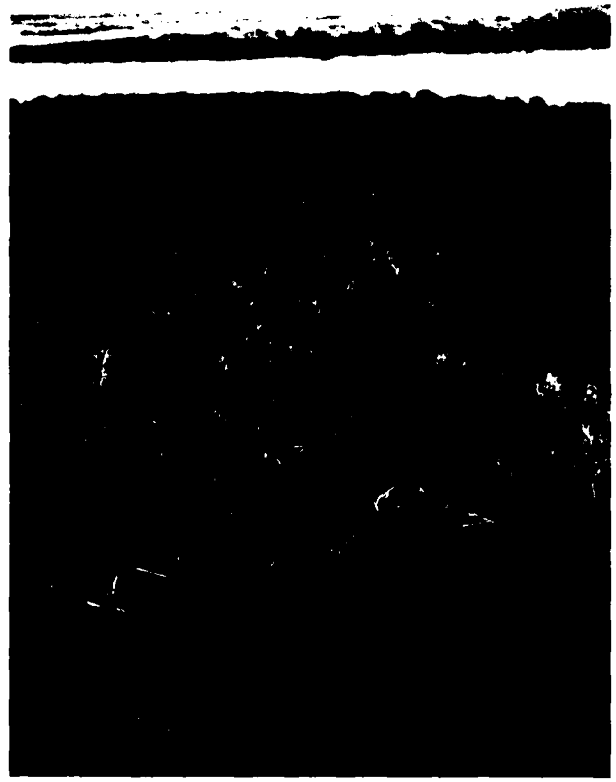
83. California least tern. The California least tern once bred in abundance along much of the lower Pacific coast. As a result of human pressures, however, both nesting and feeding habitat have been drastically reduced, resulting in a precipitous reduction of its population to the extent that it is now on the Federal Endangered Species List. The protected Huntington Beach State Park nesting population, located on the beach just west of the mouth of the Santa Ana River, is one of the largest left in the region and is a source of birds for potential colonization of any potential habitat development site if it is made suitable for nesting. The birds nest on relatively flat, barren, sandy areas, 1 metre to 3 metres above the highest tide levels. They usually prefer a stabilized sand (commonly dredged material) that will not blow in the wind, but shell and pebble substrates are also used. Least terns tolerate little or no vegetation in their nesting areas and require complete protection from disturbances by humans or other predators.

84. Belding's savannah sparrow. The Belding's savannah sparrow is a small songbird that inhabits some coastal salt marshes of southern California. Because of severe decline in its population in recent years, due mainly to habitat destruction, the bird was placed on the California Endangered Species List in 1974. The sparrow has a close association with pickleweed, spending most of its life in or near dense stands of the plant in coastal high marsh. Not only is pickleweed the preferred plant in which it builds its nest, but also the birds are known to eat the

Figure 24. Natural tidal marsh, Palo Alto, California, at low tide. Marsh is dominated by Pacific cordgrass (left) and pickleweed (right)

Figure 25. Portion of artificial marsh habitat, south San Francisco Bay, California. Pickleweed (foreground) and Pacific cordgrass (background)

a. Pacific cordgrass (Spartina foliosa)



b. Pickleweed (Salicornia virginica)

Figure 26. Example of dense stands of Pacific cordgrass and pickleweed growing in an artificial marsh habitat located in south San Francisco Bay, California

succulent growing tips of pickleweed branches.

85. Light-footed clapper rail. The light-footed clapper rail, a marsh bird of the lower littoral zone, is also on the Federal List of Endangered Species. Nesting in dense Pacific cordgrass at lower elevations, its eggs can apparently stand partial inundation. Less is known about the light-footed clapper rail than the other two birds discussed, and it has not been observed in the near-vicinity of the proposed site. However, measures promoting establishment of dense Pacific cordgrass stands in lower littoral zone situations should provide suitable habitat.

Tide characteristics off southern California

86. As noted by Newling (1979), the accurate determination of the tidal characteristics at the habitat site is crucial for the proper design and construction of the marsh topography. The tidal datum used in most coastal work is mean lower low water (mllw). Based on this datum, the National Ocean Survey (1979) tide tables indicate a diurnal tide range of 5.3 ft mllw at the coastal stations near the vicinity of the Santa Ana River mouth. Previous editions of the tide tables had indicated the same range, and the Los Angeles District (1977) determined the tidal characteristics at Newport Beach as:

Extreme high	7.5 ft mllw
Mean higher high water	5.3 ft mllw
Mean high water	4.6 ft mllw
Half tide level	2.8 ft mllw
Mean sea level	2.7 ft mllw
Mean low water	0.9 ft mllw
Mean lower low water	0.0 ft mllw
Extreme low	-2.5 ft mllw

The National Ocean Survey tide tables also indicate a station located inside the Santa Ana River entrance with a diurnal range of 3.3 ft mllw. Newling (1979) has indicated this to be the appropriate diurnal tide range for preliminary hydraulic calculations regarding filling and emptying of the artificially constructed marsh habitat area. Since the same mllw elevation would exist in either case, the Newling interpretation could only be conservative with regard to the size opening necessary

to pass a specific tidal prism. Accordingly,

Extreme high (1979)	3.9 ft mllw
Mean higher high water	3.3 ft mllw
Mean high water	2.6 ft mllw
Mean tide level	1.4 ft mllw
Mean low water	0.2 ft mllw
Mean lower low water	0.0 ft mllw
Extreme low (1979)	-0.4 ft mllw

Only a detailed study with prototype measurements of tide responses near the site will provide inundation and tidal information sufficiently accurate for final design purposes. It is questionable whether a diurnal tide range of 5.3 ft could exist in the ocean, and only a 3.3-ft diurnal range at a tide gage which is presumed to be located in the Greenville-Banning Channel near the Pacific Coast Highway. While these range values are indicated by the National Ocean Survey tide tables, the precise location of the tide gage inside the Santa Ana River entrance is not provided. Tide gage studies should be conducted at the mouth of the Santa Ana River and at all potential entrances to the marsh area before final design and construction. A distribution network of finger channels will be evaluated for effective transmission of habitat tidal prism, as well as for providing a minimum area of water surface at all times throughout the region. These channels will ensure maximum bay water-surface rise each tidal cycle.

Preliminary Hydraulic Design

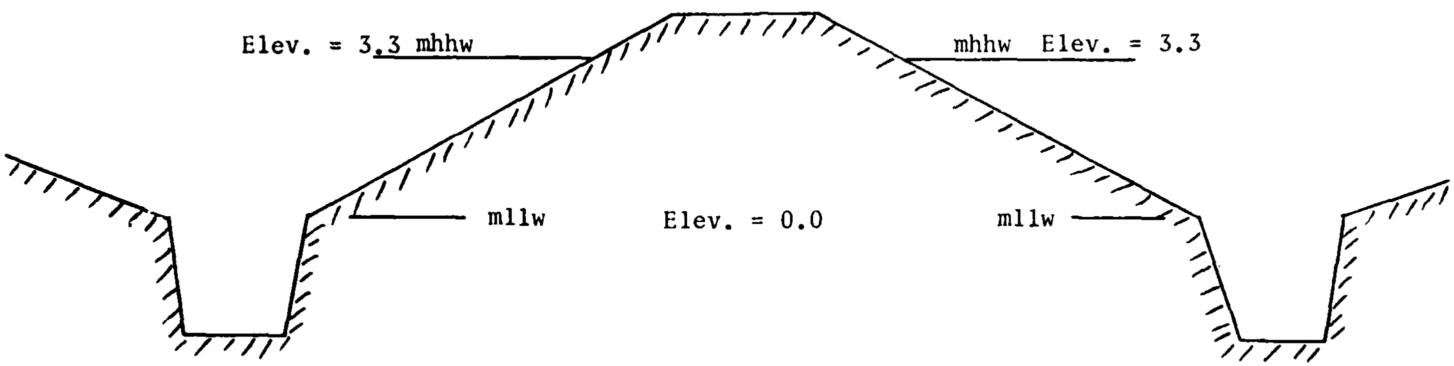
87. The specifications regarding the hydraulic characteristics of the marsh habitat development area include the fact that it is desirable to have the bay amplitude approach that of the ocean tide within practical limits. Of the total 84 acres in the development area, it is desired that 10 percent to 15 percent shall remain exposed at all times. It is also desired that 10 percent to 15 percent of the area shall be covered with water at all times. The remaining 70 percent to 80 percent is required to fluctuate between mean lower low water and mean higher

high water each diurnal tide cycle of 24.8 hours. These requirements can be adhered to by virtue of the fact that freedom exists for molding the topography to any desired configuration (schematized in Figure 27). The 84-acre development area is considered to consist of 9 acres above mean higher high water, 9 acres below mean lower low water, and the remaining 66 acres will fluctuate (fill and empty) each diurnal tidal cycle (24.8 hours).

Keulegan approximation

88. The filling and emptying of a bay or estuary connected to the open ocean by a tidal flow entrance can be analyzed to the first degree of approximation by the method of Keulegan (1967). The development of the procedure involves certain simplifying assumptions, many of which are very nearly satisfied in prototype conditions. For example, a free-surface inlet channel is considered that forms a definite flow constriction, the discharge into and from the inlet being governed by a head loss which is quadratic in velocity. The bay surface is assumed to rise and fall uniformly over the entire bay region; if the bay is fairly square or circular (or contains a distribution system of finger channels) the change in elevation of the water surface will be nearly the same for every point in the basin. A sinusoidal ocean tide was originally utilized although this is not required. The accumulation of water in the basin obeys the condition of flow for reservoirs and, in particular, the so-called "storage law." The equation representing the storage is also the differential equation of the water-surface changes. It is further assumed that there is no inflow from streams, and no density currents are present. The connecting channel is assumed to be prismatic, and the flow in the channel is assumed to obey Manning's expression for resistance under steady uniform flow conditions.

89. Because of the necessity to ensure that flooding of the Santa Ana River does not inundate Newport Shores, the consideration of the open-channel free-surface tidal inlet into the marsh area cannot be entirely fulfilled because of the channel east floodwall. The requirements of the top of the channel floodwall being constructed to an elevation of +13.6 ft mllw at the present entrance to the marsh area



Area below mllw = 9 acres
Area above mhhw = 9 acres
Area between mllw and mhhw = 66 acres

Total area = 84 acres

Figure 27. Definitive sketch for proposed artificial marsh habitat development area

indicates that a closed conduit passing through the floodwall with sufficient cross-sectional area to allow filling and emptying of the marsh area is a viable alternative. The Keulegan analysis can be approximated by ensuring that the conductance of the closed conduit is equivalent to that of an open channel of corresponding length.

90. The estuary filling and emptying "repletion coefficient," K , can be expressed after Keulegan (1967) as:

$$K = \frac{T}{2\pi a_o} \frac{A}{A_b} \frac{\sqrt{2ga_o}}{\sqrt{K_{eq}}} \tag{9}$$

where

T = period of the diurnal tide (24.8 hours)
a_o = half-diurnal ocean tide
A = cross-sectional area of the inlet channel
A_b = average bay surface area
g = gravitational constant

K_{eq} is a lumped parameter coefficient which encompasses the hydraulic resistance of the inlet proper (entrance losses, exit losses, and frictional losses along the length of the inlet channel). Hence, the characteristics of the ocean-inlet-bay system can be combined into one factor. Figure 28 shows the ratio of bay-to-ocean tide amplitude as a function of the repletion coefficient, K .

91. A stringent design requirement is that the amplitude of the bay water surface, η_b , should approach that of the ocean water surface, a_o , as nearly as practical. From Figure 28, the ratio of bay to ocean water-surface elevation increases with repletion coefficient, K , in a nonlinear and asymptotic manner. Since the repletion coefficient is directly proportional to the cross-sectional flow area of the inlet channel, an infinitely large channel would be necessary to produce a bay water-surface elevation exactly equal to that of the ocean. However, approximately 98 percent of the ocean amplitude can be achieved with an opening sufficient to provide a repletion coefficient of 1.92. Hence, the problem for solution is the determination of culvert sizes in the

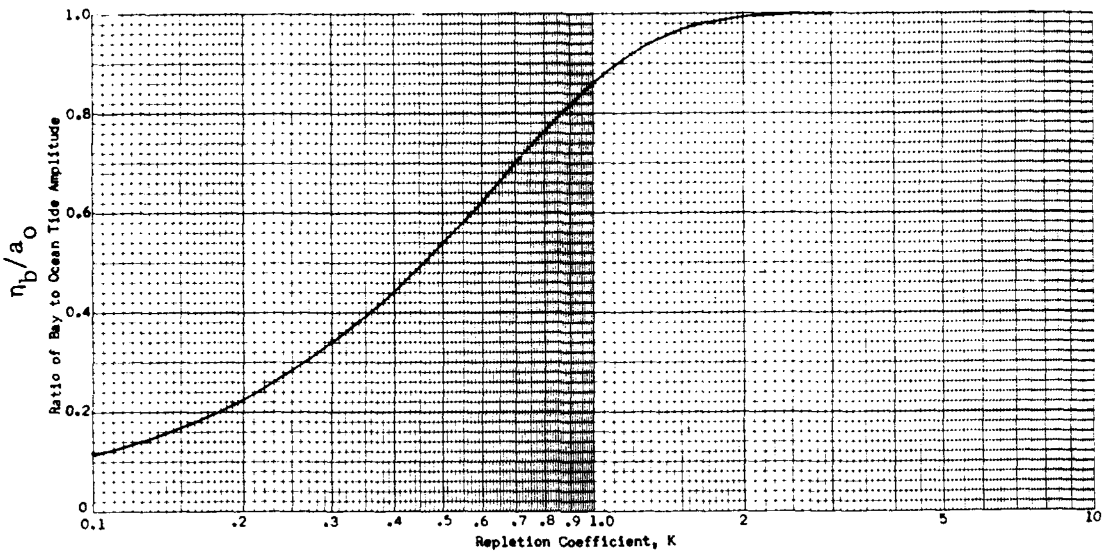


Figure 28. Keulegan's "repletion coefficient," K , versus ratio of bay-to-ocean tide amplitude (after Keulegan 1967)

presence of a 3.3-ft tide range which will provide a repletion coefficient of approximately 1.92.

92. The total energy losses across a section of pipe consist of entrance losses, exit losses, and frictional losses along the pipe.

$$H_L = H_{en} + H_{ex} + H_{fl} \tag{10}$$

$$H_L = (K_{en} + K_{ex} + K_{fl})V^2/2g \tag{11}$$

where the energy losses are expressed in terms of the velocity head, which in turn is based on the average velocity of flow, V , through the pipe. For a square-edged entrance, $K_{en} \approx 0.50$. $K_{ex} = 1.00$ identically, and:

$$K_{fl} \simeq 29n^2L/R^{4/3} \tag{12}$$

where

n = Manning's coefficient of roughness
L = length of each pipe
R = hydraulic radius of the pipe section

Assuming a 4-ft-diam section of concrete pipe 20 ft long with a typical roughness of $n = 0.013$, the cross-sectional area, A, equals $12.57\ ft^2$, and the hydraulic radius, R, equals 1.00. Hence, $K_{fl} \approx 0.10$. Defining:

$$K_{eq} = K_{en} + K_{ex} + K_{fl} \tag{13}$$

$K_{eq} \approx 1.60$ for these conditions.

93. The area of the marsh region fluctuates between 9 acres and 75 acres within a period of 24.8 hours; hence, the average bay area during the cycle is 42.0 acres. Under these conditions, and by utilizing Equation 9, $K = 0.48$ per each 4-ft-diam section of concrete pipe. For four sections of such pipe, $K = 0.48 \times 4 = 1.92$, the conductance of which is sufficient to provide approximately 98 percent filling and emptying of the bay each 24.8 hours, in the absence of significant vegetation which might adversely affect the storage relationship of the opening/bay system. At the time of the completion of the marsh development area, vegetation will be minimal, and the four sections of 4-ft-diam concrete pipe appear to be adequate. However, after marsh grass growth has become fully established, the resistance to water movement will have increased. The effects of channel overflowing and flooding of overbank river regions are known and have been studied intensively under steady-state conditions. The nonsteady, nonuniform flow conditions created by the dynamic forces of tidal actions are not as well understood. Chow (1959) indicates that the effect of heavy vegetation may be to increase the resistance to the conductance of flow by as much as 50 percent. Under these considerations it is believed that six sections of 4-ft-diam culvert will transmit a tidal prism sufficient to allow for almost maximum bay rise after significant vegetation has established. In order to provide the minimum 9 acres of water surface at mllw, it will

be necessary to construct a system of distribution channels throughout the habitat. Assuming a channel width of 50 ft at low tide, approximately 7,900 lin ft of channel will be required. These channels can be arbitrarily arranged to provide a potential outlet at the existing or any other desired location along the Santa Ana River flood channel. In fact, to provide for maximum flushing of the channels, two different locations of three culverts each could be considered. A potential layout of the distribution channels and outlet locations are shown in Figure 29.

Numerical approximation

94. Because the Keulegan approximation was developed for circumstances slightly different from those to which it is presently being applied, it was desired to confirm the estimation provided by this technique. Using the geometry deduced from the Keulegan method, a one-dimensional numerical analysis was conducted that applied the bay configuration proposed for the habitat (shown schematically in Figure 27) instead of the average bay area previously used. The forcing function was considered to be a sinusoidal ocean tide, although any arbitrary water-surface rise of the ocean elevation could have been programmed. The numerical technique computes the flow through the culverts during a finite interval of time, considering the hydraulic resistance to flow afforded by the culverts themselves, and assuming the ocean tide had risen or fallen an appropriate amount during this finite interval of time. For the analysis, a time interval of 30 sec was chosen and the four 4-ft-diam concrete culverts deduced by the Keulegan method were considered. Starting with the ocean and bay at mllw, the elevation of the ocean was determined after 30 sec. With this new ocean water-surface elevation and the bay water-surface elevation from the previous time, a head differential existed across the culverts which induced flow through the culverts into the bay. This volume of flow over the 30-sec time interval effected a rise in the bay water-surface elevation which could be determined since the bay water-surface area at all elevations was known from the preformed geometry of the habitat. This technique was cycled through for the 24.8-hr diurnal tide in increments of 30 sec, and

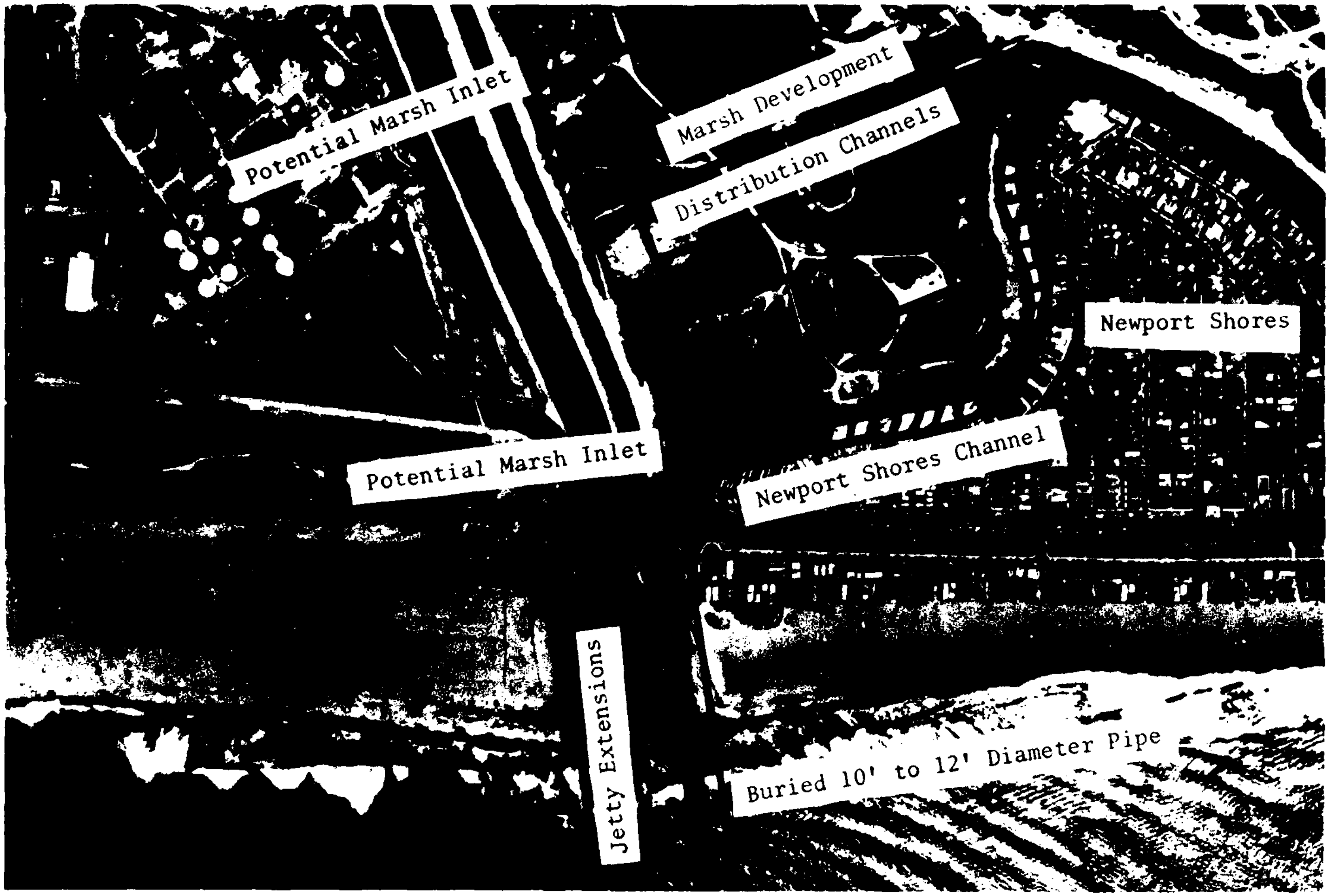


Figure 29. Alternative potential solutions to marsh development problems at mouth of Santa Ana River, including jetty extensions, buried pipeline, and culverts through floodwall

it was determined that when the ocean tide rose 3.3 ft, the bay water-surface elevation rose 3.24 ft, or approximately 98 percent of the ocean rise as indicated previously by the Keulegan technique. When only three 4-ft-diam culverts were installed, the bay water-surface elevation rose to 3.15 ft, or approximately 95 percent of the ocean rise. These data are shown in Figure 30 for the time intervals near mean higher high water. A similar mathematical model was applied by Tucker et al. (1975) to the analysis of the Palo Alto, California, marshland rehabilitation project.

95. In order to provide viable alternatives, three sections of box culverts were considered for this installation. Since the Santa Ana River carries a tremendous sediment load under flood flow conditions, there exists the possibility that deposition or shoaling may occur in the vicinity of the entrance to the marsh habitat area. It was assumed for the box culverts (as well as for the round culverts) that the top of the culvert was placed at mllw, thus ensuring that full conduit flow was taking place under all head differentials. A 4- x 12-ft box culvert (or three 4- x 4-ft culverts or four 4- x 3-ft culverts) was evaluated, and the bay water-surface elevation was found to rise to 3.23 ft mllw. When 1 ft of silt was assumed to have been deposited in this reach, there was left effectively a 3- x 12-ft box culvert (or three 3- x 4-ft culverts or four 3- x 3-ft culverts), in which case the bay water-surface elevation rose 3.13 ft or 95 percent of the ocean rise. A 3- x 15-ft box culvert (or three 3- x 5-ft culverts or five 3- x 3-ft culverts) also was investigated, and the bay water-surface elevation was found to be 3.21 ft. These data are presented in Figure 31.

96. Another problem closely aligned with the marsh development situation is the possibility that large amounts of littoral drift during the summer months may form a blockage of the Santa Ana River mouth, thus preventing the exchange of tidal flow through the culverts into the marsh habitat development area. Accordingly, a pipeline buried beneath the Santa Ana River flood channel bottom and extending into the ocean to a point where the water depths approach 20 ft mllw was considered, even though this may not provide a free and biologically unimpeded exchange

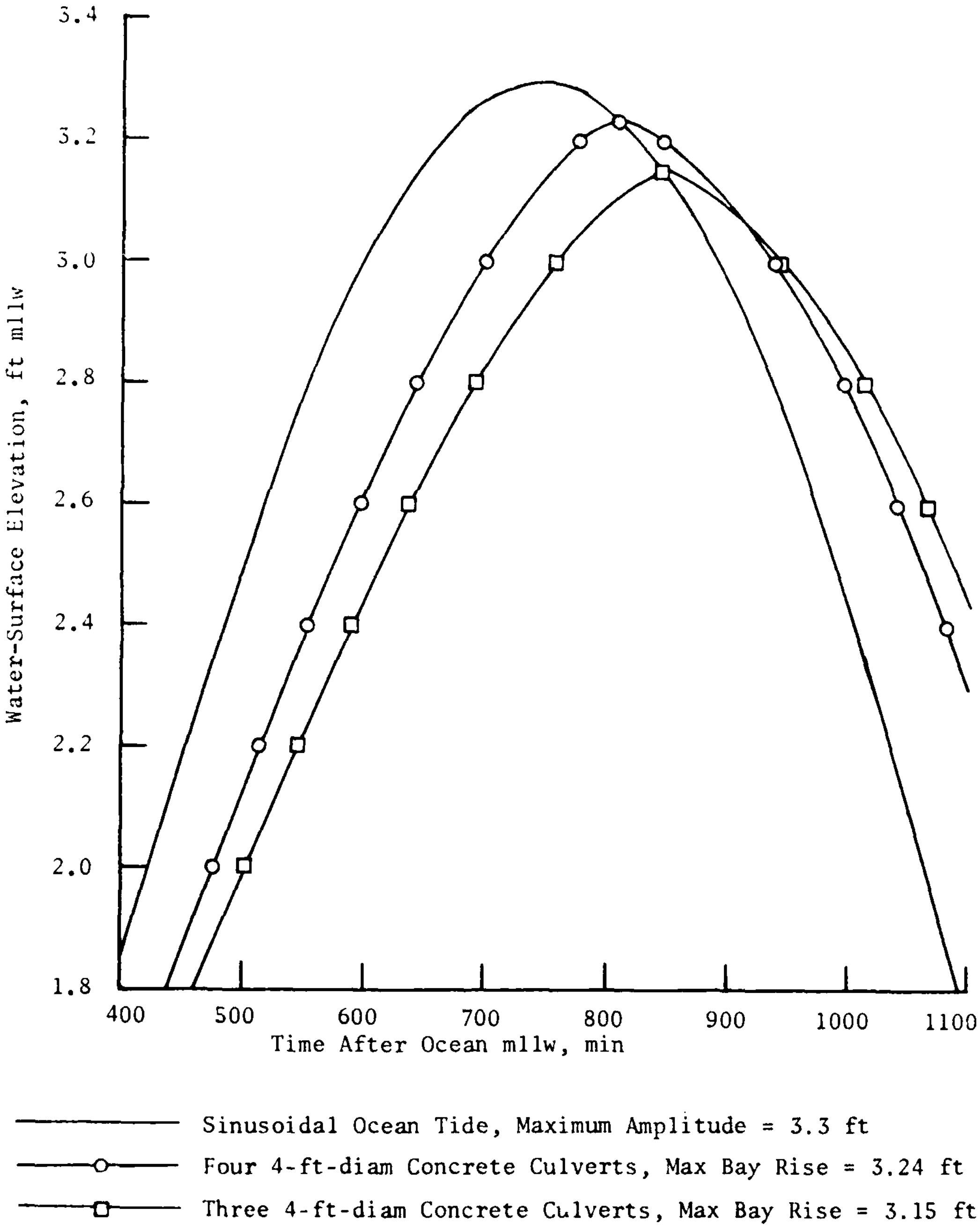


Figure 30. One-dimensional numerical computations of bay water-surface elevation versus ocean tide for three and four 4-ft-diam culverts

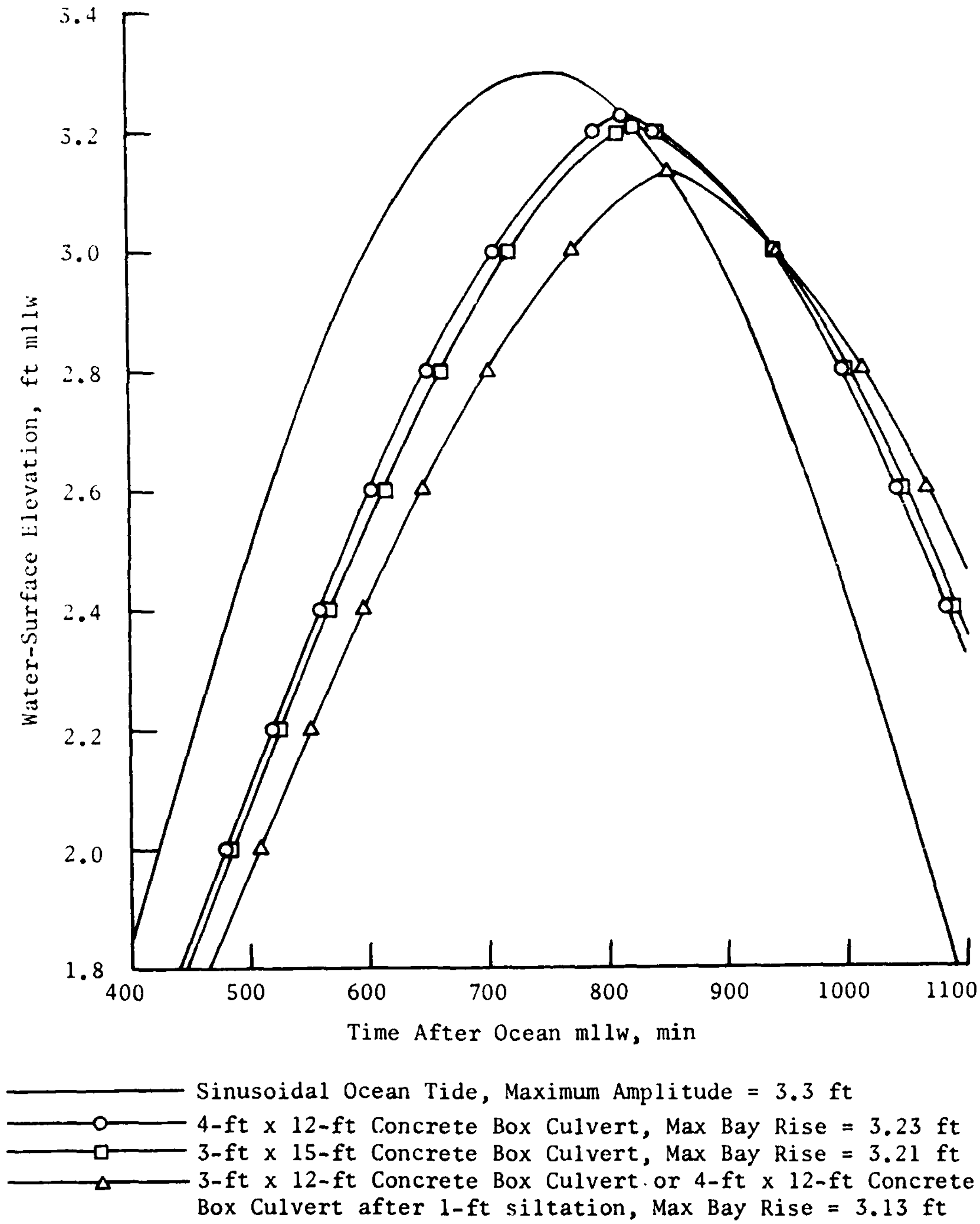


Figure 31. One-dimensional numerical computations of bay water-surface elevation versus ocean tide for various box culvert sizes

of water. The potential pipeline length was estimated to be around 2,000 ft. The diameters required to transfer significant amounts of tidal flow into and out of the marsh area were estimated to be 10 to 12 ft, producing bay water-surface elevations of 3.16 and 3.26 ft mllw, respectively. Moffatt and Nichol (1973) had previously considered the installation of a 10-ft-diam pipe under the Pacific Coast Highway at the east end of the Newport Shores Marina to alleviate poor water quality in the marina but had determined that solution to be economically infeasible for that purpose. However, the importance of the creation of a successful habitat may lend greater credence for this application. Results of these computations are shown in Figure 32.

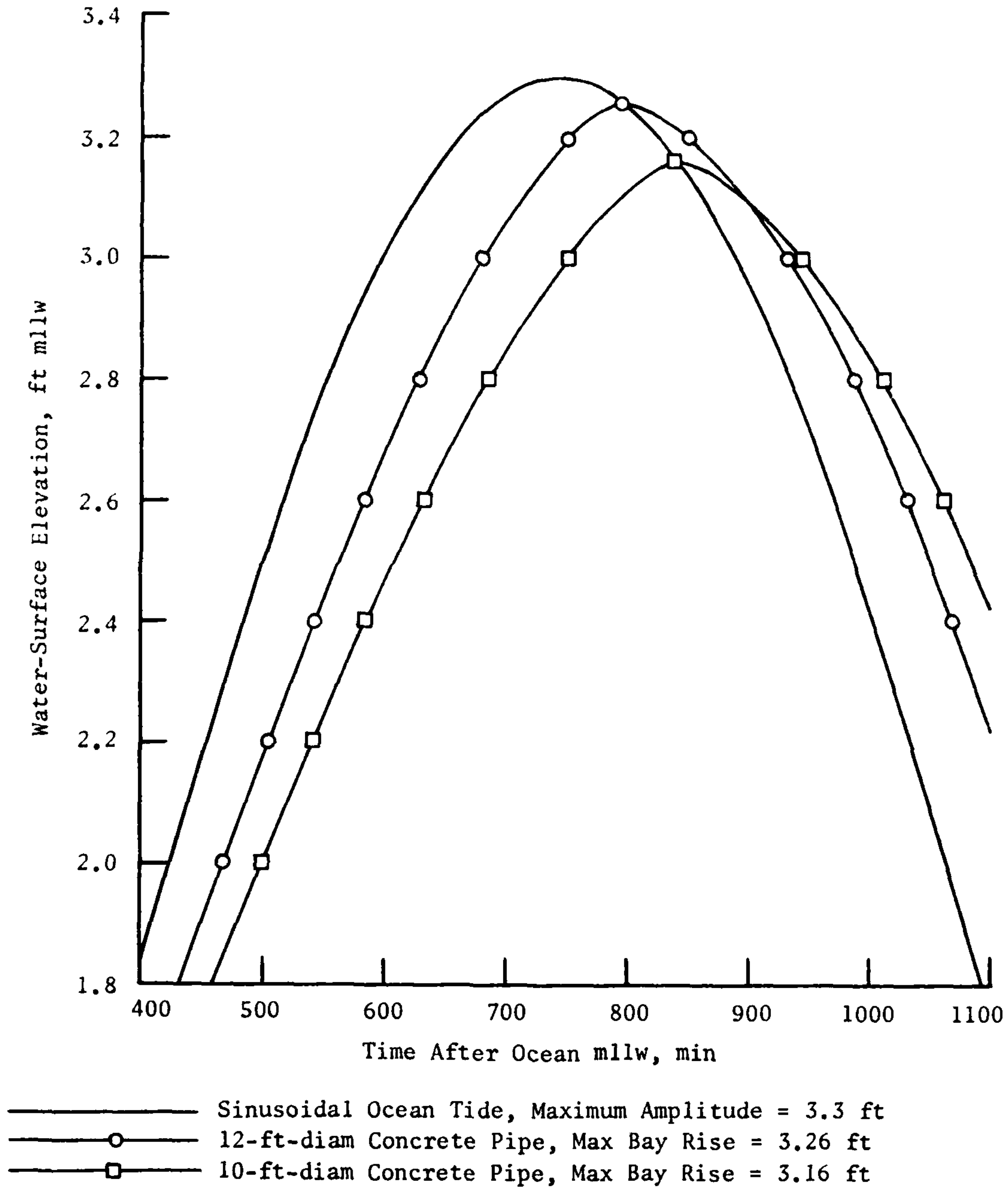


Figure 32. One-dimensional numerical computations of bay water-surface elevation versus ocean tide for 10- and 12-ft-diam pipeline

PART VI: POTENTIAL ALTERNATIVES FOR MAINTAINING SANTA ANA RIVER MOUTH OPENING

97. The closure of river mouths by littoral sedimentation action is a natural condition at several river outlets in southern California. Flood damages induced by floodwater inundating low-lying floodplain land before the blockage is either breached or overtopped can be substantial, especially in urbanized areas. The blockage also prevents the free exchange of tidal water for biological or other purposes. Solutions to the problem may be achieved by preventing the formation of the sand plug by the use of jetties or other structures, or by successive breachings of the blockage during its formation. Generally, three major factors contribute to the formation of a sand plug at a river mouth: (a) small tidal prism, (b) large wave power, and (c) little or no (intermittent) streamflow. Two approaches toward a solution of the inevitable problem are possible. One approach is to prevent the formation of the sand berm across the river mouth, and to keep the mouth open permanently by altering the natural conditions of the river. A second approach is to allow the sand plug to form but to cause breakage of the berm prior to the arrival of peak floodflows (feasible only if floodwater inundation is the major concern). Mechanical dredging and structural measures are effective although expensive. However, hydraulic structures are in use that utilize the hydraulic forces of early arriving storm flow (or regulated river discharge) to breach the blockage. When positioned properly in the river mouth, these structures will induce piping and erosion of the sediment plug progressively from the ocean side toward the upstream region.

98. Several potential alternatives exist for maintaining an opening at the Santa Ana River mouth to ensure tidal exchange with the marsh habitat development area. Some alternatives will be more cost-effective than others, and no detailed cost estimates have been prepared for any of the potential alternatives. From a conceptual feasibility standpoint, several possibilities are advanced for consideration. Because the problem associated with ensuring an opening at the river mouth results from complex physical processes and uncertainties inherent to the wave climate

variability, the situation is extremely difficult to investigate analytically. A much better understanding and appreciation of the coastal processes of the river mouth vicinity could be obtained with a physical hydraulic model investigation. At the present time it is not at all clear which potential solution is optimal, or even which ones will function to solve the problems since some alternatives are more susceptible to failure if gross disparities occur in the sedimentation rates. This section is intended to provide only order-of-magnitude estimates for comparative purposes. Absolutely no detailed design or detailed cost estimate for any system has been prepared at this time.

Santa Ana River Jetty Extensions

99. An extension of the Santa Ana River west and east jetties into the surf zone for a distance sufficient to prevent sand migration around the ends of the jetties will effectively prevent the formation of the sand block at the mouth of the river by littoral material. The jetty extensions should be sealed or otherwise made impermeable to sand transmission through the jetties. Such extensions will also prevent the transport of littoral drift upcoast and downcoast seasonally. However, since there is a significant amount of beach material drifting south and away from the Surfside-Sunset Beach region toward Huntington Beach, and less material drifting south and away from the Huntington Beach region, the section of beach near Huntington Beach and the Santa Ana River mouth is being sustained by net input from the north, as long as the feeder beach is maintained. Jetty extensions into the surf zone at the river mouth will tend to widen the beach on the west side of the river. Because the net drift is to the southeast in this region, no detrimental effects to the beaches on the west side of the river are readily apparent.

100. The beaches on the east side of Santa Ana River are receiving nourishment from the area west of the river at the present time, but this material is apparently passing along the surf zone since the groin field on the east side of the river appears to be maintaining a stabilized section of beach. Hence, that material presently passing the river

mouth is being transferred unimpeded downcoast past the groin field, and the City of Newport Beach has indicated that the City is satisfied with the present beach configuration. However, significant capacity exists for the placement of a large quantity of beach-fill material to be excavated from the Santa Ana River widening and deepening. Up to 650,000 cu yd of material could be placed in the existing groin field, and an additional 350,000 cu yd could be placed between the Newport Beach west groin and the Santa Ana River proposed east jetty extension (Figure 33). The groin field commences approximately 4,500 ft east of the east river jetty.

101. The concern of the City of Newport Beach about the possible placement of a large quantity of material in the groin field has been expressed by Wynn*:

> ".....I have reviewed your letter of 12 February 1980 regarding the placement of approximately 1,000,000 cu yd of sand from the Santa Ana River on the West Newport beach.....Because of the large quantity of material involved, it would seem that the beach configuration could undergo a major shift to a new equilibrium condition. If the sand is placed so that it can be acted upon by the waves, what will be the new beach profile? A major change in profile would probably not be in the City's interest. As an example of undesirable change, the beach front between the Balboa Pier and the harbor entrance is a very steep beach profile and consequently, is not a good swimming or surfing beach. This beach was made of harbor dredged material and considerably altered the beach profile.....If any of the material from the Santa Ana River is placed landward of the berm, so that the waves do not act upon it, then the fill should have the same esthetic and composition qualities as the existing beach sand material.....Perhaps the proposed project should incorporate a plan to gradually release some fill material into the surf zone along the entire

*Robert L. Wynn, City Manager, City of Newport Beach, personal communication to Mr. Norman Arno, Chief, Engineering Division, U. S. Army Engineer District, Los Angeles, 26 February 1980.

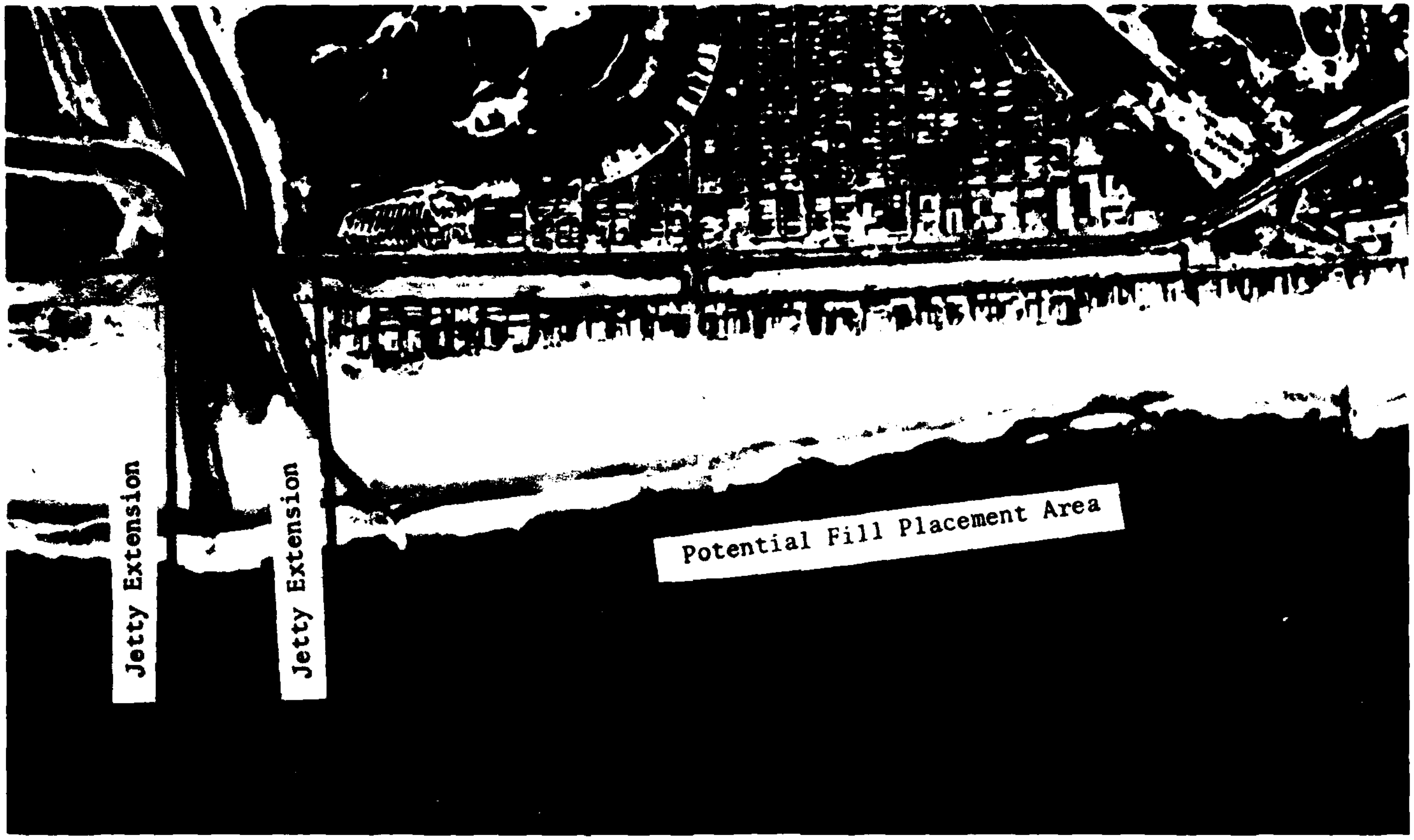


Figure 33. Potential extension of the Santa Ana River jetties into the ocean to a distance sufficient to prevent blockage of river mouth by littoral drift. Placement area would be provided immediately east of the river for beach nourishment material

West Newport stretch of beach so as to allow the
wave induced transport to disperse and clean it.
.....It appears that the West Newport Beaches have
reached somewhat of a stable or equilibrium state
since completion of the groins. The City has not
experienced any major areas of erosion along these
beaches in the last few years. Consequently, the
City is extremely sensitive to first altering the
quality of sand that currently exists and the
potential for changing the beach profile.....I
believe that the City Council will want a plan
that guarantees that material, if placed on
West Newport beaches, be as good or better than
the existing material and that the material be
placed into the surf zone so that any pockets
of silt material can be cleaned by the surf zone."

The section of beach containing the groin field under consideration is shown in Figure 34.

Figure 34. Newport groin field, potential placement site for substantial amounts of beach nourishment material to be excavated by widening and deepening the Santa Ana River flood-control channel

102. The extension of the jetties into the surf zone for a distance sufficient to obtain a water depth where wave motion will not be felt on the bottom is, of course, impractical. More realistically, the jetties should extend to a depth such that bottom movement will be experienced for only a small percentage of the time. Long-period southern hemisphere swell with a period of greater than 18 sec occurs for less than 1 percent of the year. The horizontal velocity component of the water particle motion, u , is expressed by Sorensen (1978) as:

$$u = \frac{\pi H}{T} \frac{\cosh k\,(d + y)}{\sinh kd} \cos\,(kx - \sigma t) \tag{14}$$

where

H = wave height
T = wave period
d = water depth
y = elevation below msl
k = wave number, $2\pi/L$
σ = wave angular frequency, $2\pi/T$

Considering an 18-sec wave period with a height of 4 ft occurring in water 20 ft deep below mean waterline, the horizontal wave motion velocity felt on the bottom will be around 2.50 fps. This velocity is sufficiently adequate for transporting sediments existing along the coast of southern California. However, because of the low frequency of occurrence, the total volume of material moved by this wave will not be untenable.

103. Based on the existing hydrographic surveys of the ocean region near the mouth of the Santa Ana River, and applying guidance for design of breakwaters and jetties (Office, Chief of Engineers 1963), the following quantity estimates were deduced. In order to reach a water depth of 20 ft, the jetties will have to extend approximately 1,000 ft farther into the surf zone than the proposed design at the present time. Building to a finished grade elevation of +8 ft mllw, ocean-side slopes of 2H on 1V, and channel-side slopes of 1.5H on 1V, an estimated 112,600 tons of stone will be required (unit weight 165 lb/ft^3) if the structure has a porosity of 38 percent. At an estimated unit cost of \$20 per ton for placed stone in this region, the cost for construction of both the

east and west jetty extensions is estimated to be about $2.2 million. This appears to be a permanent solution with no additional operation cost involved, and the probability of a successful operation is considered moderate to high.

Mechanical Removal by Dragline

104. Because the sand blockage problem is a seasonal phenomenon, the utilization of a mechanical dragline system operating from the east floodwall side of the channel may be considered as an alternative. During the months of July, August, September, and October, southern hemisphere swell transports a quantity of material north sufficient to cause complete blockage of the river mouth in the absence of mechanical assist techniques. Periodic and timely removal of a portion of this material may be sufficient to effect tidal exchange up the Santa Ana River lower section. However, the duration of the removal process may be prohibitive as the river mouth has been observed to be completely blocked through the month of December.

105. The estimated cost of a dragline and crane with sufficient capacity and length (including appurtenance vehicles such as transfer and fueling trucks) is about $0.3 million. Additional annual operation costs are estimated to be about $20,000 per month. Since there is no certainty regarding the manner in which the littoral material will accumulate near the east floodwall, the effectiveness of this procedure cannot be assured without substantiating physical model investigations. Hence, the viability of maintaining a tidal opening simply by removing sediment accumulation with only a dragline is questionable, and the probability of success is considered low.

Auxiliary Wall and Dragline

106. Since there is a reversal in direction of the littoral drift each month in this region, portions of the gross transport from the west may be of a magnitude large enough to overwhelm a dragline capacity. In

this case, construction of a wall parallel with the east floodwall will provide a finite section of the river mouth to be maintained. When the major portion of the river mouth is removed from consideration, all tidal flow will be restricted to the maintained part and thus contribute the tidal prism flushing effects toward removal of sand accumulation (Figure 35). The auxiliary wall could be fashioned of vertical sheet-steel piling driven into the earth bottom of the flood channel and extending from the designed grade of the new channel to mean high water. This distance is approximately 10 ft, and standard construction procedures when working with sheet-steel piling is to provide for a penetration depth about twice that which is protruding. Accordingly, the sheet-steel pile would require a total height of 30 ft for a channel length of about 1,200 ft. The unit cost of placed sheet-steel pile (typical section Z-27) is estimated to be $15 per sq ft; thus, the order-of-magnitude estimate for the construction of the sheet-steel pile wall is $0.6 million, including mobilization and demobilization costs. The viability of maintaining the tidal opening by using a dragline (previous estimate of $0.3 million) to remove sediment accumulation between the Santa Ana River flood channel east wall and the auxiliary wall is considered low to moderate, with the total installation cost estimated to be about $0.9 million.

Floodgates

107. The Savannah River at Savannah, Georgia, is divided into two channels by Hutchinson Island. The Front River, relatively narrow and deep, serves as a navigation channel. In contrast, the Back River is broad and shallow and not suitable for navigation. To minimize the need for maintenance dredging in the Front River navigation channel, the U. S. Army Engineer District, Savannah, constructed a series of 14 tide gates in a structure across the Back River (Weggel, Roberts, and Hagar 1979). The gates open during flood tide and allow upstream flow in the Back River but close during ebb flow and force all of the tidal discharge out

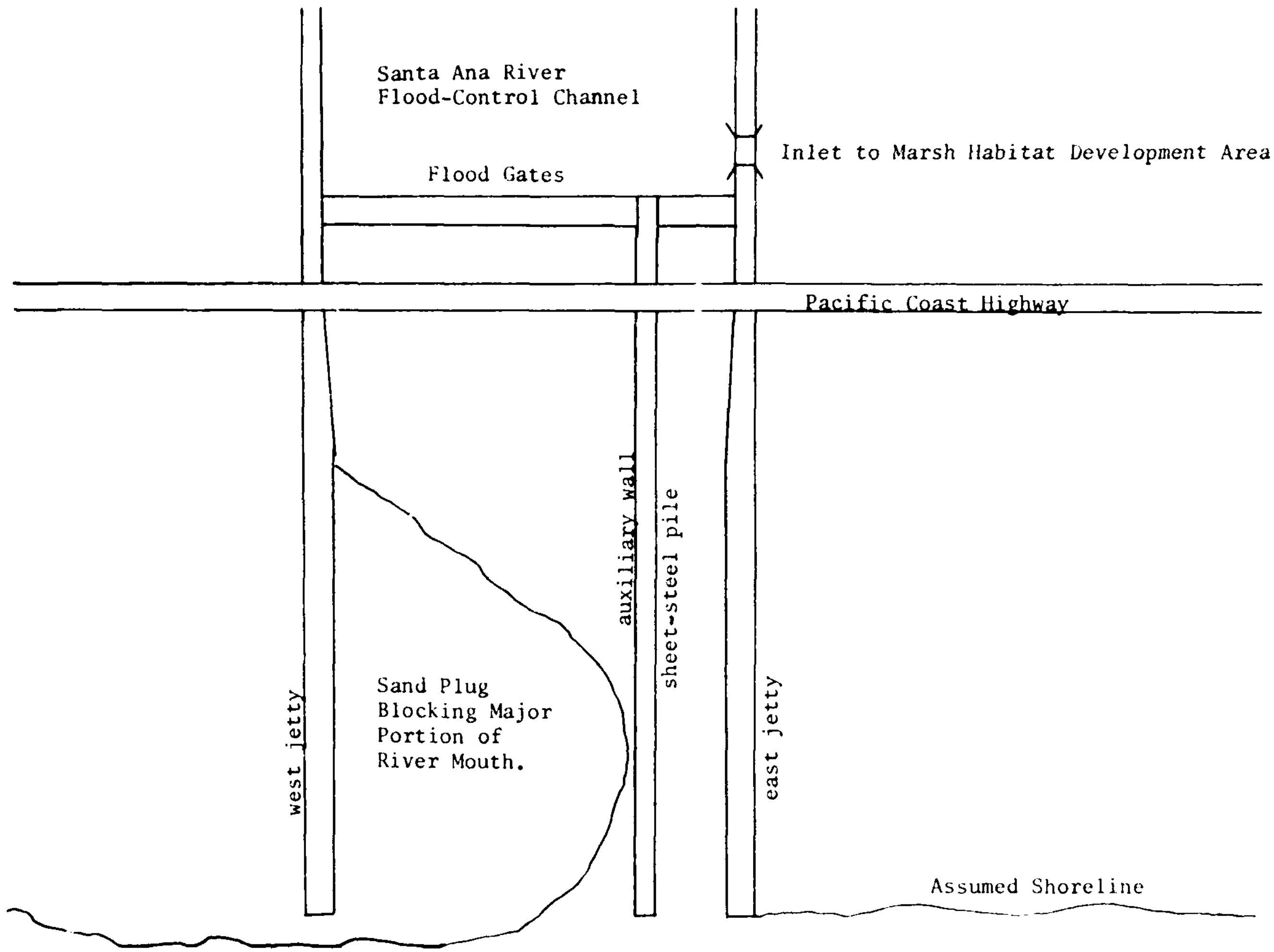


Figure 35. Auxiliary parallel wall conceived to operate in conjunction with mechanical dragline or floodgate system (either manual or automatic)

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LITTORAL PROCESSES STUDY, VICINITY OF SANTA ANA RIVER MOUTH FRO--ETC(U)
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through the Front River, thereby flushing sediments from the navigation channel (Figure 36).

108. The 14 tide gates each weigh 43,000 lb, are approximately 40 ft wide, 27 ft high, and pivot about an axis 18 ft above the gate sill. When in a closed position, each gate makes an angle of about 73 deg with the horizontal. The gates can be operated (raised or lowered) by means of a double-acting hydraulic cylinder that connects the center top of each gate to a reinforced concrete reaction beam that runs the entire length of the gate structure. As originally planned, the gates would be controlled by an active system that would open and close them in accordance with predicted tides. It was later determined that passive operation of the gates with the actual water level differential across the gates opening and closing them would be a better mode of operation since it would not rely on the accuracy of tide predictions.

109. The permanent installation of a system of flood-control gates near the inlet of the marsh habitat area should be evaluated. The purpose of these lift gates (either vertical lift or pivotal) would be

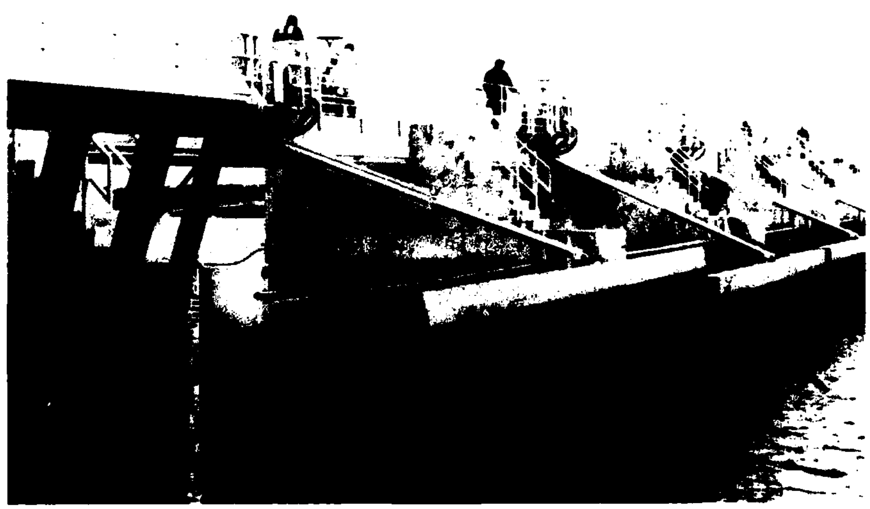

Figure 36. Savannah River tide gates (1979 photograph by CERC)

to allow complete tidal prism inflow on the flood tide, to temporarily retain the tidal prism until the ocean tide level had receded, at which time the gates would be opened. This would permit the greatest head available to induce scouring velocities and flush away any accumulated sand blockage from the mouth of the Santa Ana River. Systems of flood gates of a magnitude required to control flow of tidal prism on the Santa Ana River are routinely in operation throughout Europe, particularly in the lowlands of the Netherlands. The Savannah River tide gates (total length 560 ft) were constructed at a cost of approximately $4.0 million. Extrapolating to the Santa Ana River site, an order-of-magnitude estimate of the construction cost is $3.5 million. The opening and closing could be programmed with the astronomical tide for automatic operation, or a system that operates on the head differential across the gates could be installed. In either case, the tide gate concept is considered to have a low to moderate probability of success.

Floodgates and Auxiliary Wall

110. If the floodgates described above were installed in conjunction with the auxiliary sheet-steel pile wall previously discussed, the tidal prism inflow on the flood stage could be regulated through the smaller channel near the east floodwall on the ebb tide condition. This would permit the greatest head available to induce scouring velocities in the small channel and thus maintain an opening for tidal exchange with the marsh area. The order-of-magnitude cost estimate of the combined system should approach the total of the two separate concepts, being $3.5 million and $0.6 million for a total estimate of $4.1 million. However, because of the uncertainty regarding the accumulation of sediment in the wider section of the flood channel, the probability of success can only be considered again as low to moderate, in the absence of substantiating physical model data. The combined feasibility concept is illustrated in Figure 35.

Pipeline

111. As discussed previously regarding the guarantee that an adequate amount of tidal flow would pass through the floodwall into the marsh habitat area, a buried 10- or 12-ft-diam pipeline beneath the bottom of the Santa Ana River will apparently meet those requirements. However, it is questionable whether aquatic species will traverse a 2,000-ft length of sunless pipe and provide a desirable biological exchange with the open ocean. Therefore, while the discharge of water may be sufficient for filling and emptying the marsh habitat area, the system may not be acceptable from the standpoint of failure to provide free movement of marine life. The pipeline is envisioned as extending from the marsh area to the -20 ft mllw contour in the ocean, a distance of approximately 2,000 ft. The order-of-magnitude unit cost for pipe of this diameter in place is $2,000 per lin ft. Hence, the total estimated cost is about $4.0 million, and the probability of success can only be considered as low because of possible lack of biological exchange.

Jet Pump System*

112. The mouth of the Santa Ana River is characterized by a broad delta caused by the combined effect of surface wave action, longshore transport, and periodic river discharge. A berm with elevations above mean higher high water forms during periods of low river discharge and extends completely across the river mouth. This berm eliminates tidal exchange between the ocean and riverine systems. The diurnal tidal range at this site is approximately 3.3 ft.

113. Future development of a salt marsh adjacent to the river will require that there be a free and biologically unimpeded exchange of water through the river mouth. Maintenance, by means of a jet pump

*This section was prepared by J. C. Roberge and T. W. Richardson, Research Hydraulic Engineers, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

sand bypassing system, of a free surface water exchange pass through the berm, coupling the ocean and river system, was considered.

114. The following general assumptions and considerations were made preliminary to the formulation of the Santa Ana River mouth jet pump sand bypassing concept:

- a. Adequate information and data do not exist for the development of a preliminary jet pump sand bypassing system design at this site.

- b. The site is considered to be not well suited for implementation of a jet pump system. Transport and deposition patterns are not defined over the broad delta, and access to clear water for the system supply pump(s) is limited and subject to blockage.

- c. Description of the jet pump sand bypassing concept for the Santa Ana River is based upon system designs for other sites with similar littoral climates. Estimates at Santa Ana are annual longshore transport of approximately 497,000 cu yd northerly and 609,000 cu yd southerly (i.e., 112,000 cu yd net southerly transport and 1,100,000 cu yd gross annual transport).

- d. The system concept described herein should not be used for any engineering design or construction planning and is intended to serve only as a feasibility concept for comparison with other alternatives.

- e. Discharge distances are not known; therefore, discharge line booster stations are conceived as unit modules that can be included in the discharge line as dictated by required pumping distance.

- f. Detailed location criteria and final positioning of the jet pumps are not discussed in this development.

- g. Pumphouse elevation and structural rigidity are dependent upon design water-surface elevations and wave conditions; development of these parameters are beyond the scope of this discussion.

- h. Operation of the system was assumed to be manual, thus requiring minimum automation.

115. Nine jet pumps could be located in the improved Santa Ana River mouth and oriented perpendicular to the assumed shoreline such

that a channel might be maintained through the berm formation. The main pumphouse, containing a discharge booster pump and supply pump(s) can be situated in the right-of-way immediately to the south of the river mouth. Slurry booster pumps can be incorporated into the discharge line as required.

116. The major mechanical components of a system capable of performing the mission required at the Santa Ana River mouth are summarized in Figure 37. Personnel requirements for the manually operated system are as follows: (a) two operators at the primary pumphouse, (b) one operator at each booster module, and (c) one operator at the discharge area.

117. A jet pump sand bypassing system has been designed in detail for installation at Oceanside Harbor, California, where the littoral regime is of the same order as that in the vicinity of the Santa Ana River mouth, both on a net and gross basis. The monthly distributions are different, of course, because of the local bathymetric effects and because of the differences in wave exposure windows due to island sheltering. A dual system has been designed for this location due to the necessity to bypass sediment in both directions at different times of the year. Based entirely on the estimated detailed cost of installing the dual sand bypassing system at Oceanside, it is extrapolated that a single system for the Santa Ana River mouth would cost approximately $3.0 million (an order-of-magnitude estimate). Due to the many uncertainties discussed by Roberge and Richardson, the probability of successfully operating such a system at the Santa Ana River mouth can be regarded only as low to moderate.

Hydraulic Structure

118. As in southern California, many rivers and streams of the Hawaiian Islands experience total blockage of their mouths at times of low riverflow. Maintaining perennially open inlets on some of these rivers requires excessive costs. The present methods being implemented in Hawaii include the construction of jetties, dredging, and the use of

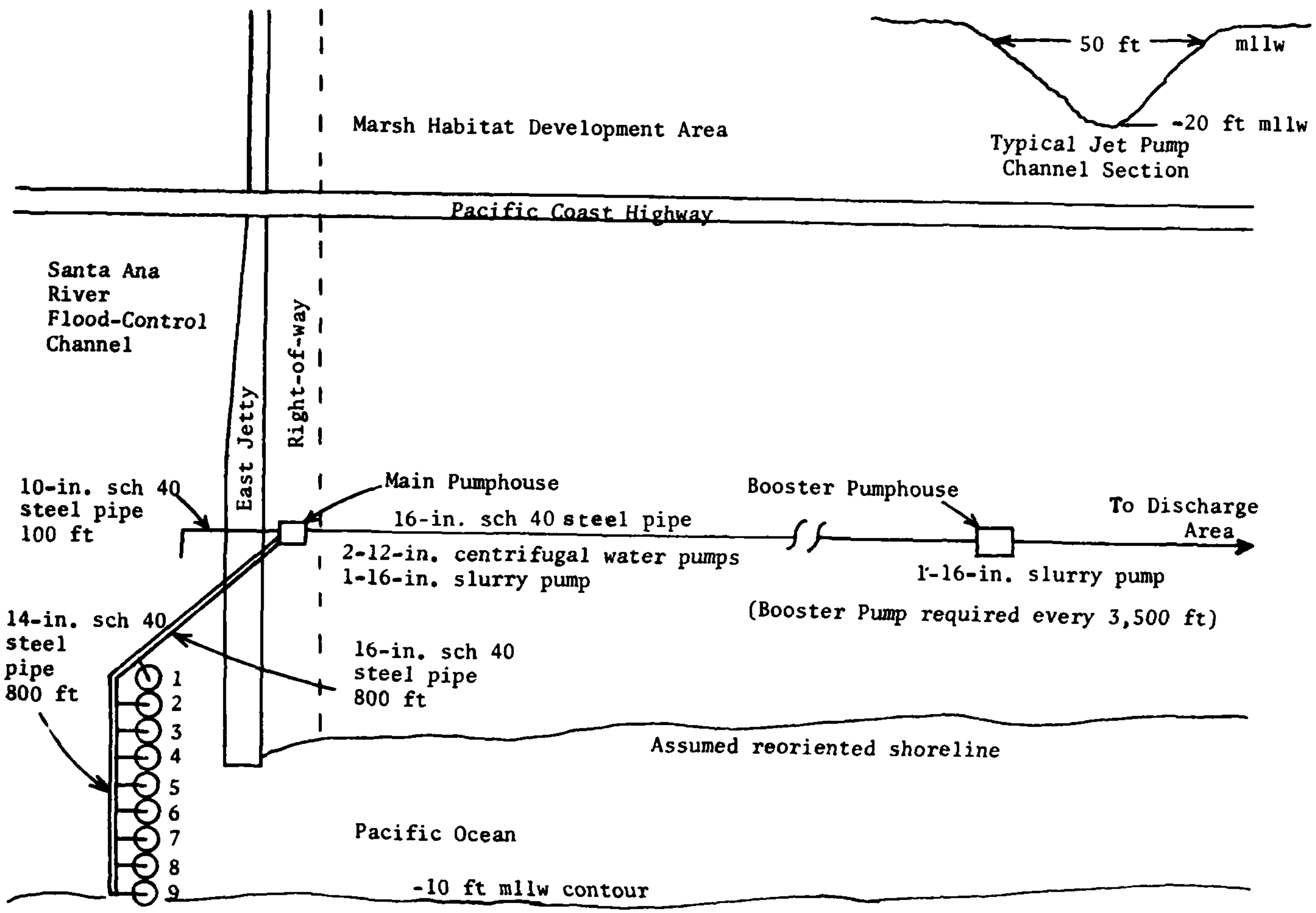

Figure 37. Jet pump sand bypassing concept developed for maintaining a free tidal exchange

unique hydraulic outlet structures that are, for the most part, self-cleansing; i.e., the initial streamflow induces piping action which sloughs the sand berm away. The jetties are effective deterrents to river mouth closure, but they are not always feasible for small streams. Dredging is virtually ineffective in relieving the problems on some of the streams because the littoral sediment often again plugs the mouth within a matter of a few days.

119. An innovative type of hydraulic structure has been developed by U. S. Department of Agriculture, Soil Conservation Service, and installed at three different river mouths on the Island of Oahu (Nishimura and Lau 1979a, 1979b). These structures (Figures 38 and 39) were designed to hydraulically breach the sand berms by utilizing early arriving storm riverflow as eroding agents. Basically, the structure consists of culverts which channel the storm water into and through the sand berms through slots positioned along the bottom of the culverts. The prototype structures have performed adequately on most occasions for those conditions for which they were designed. Their operation requires riverflow from upstream to initiate the piping and scouring action. Under these stipulations, the release of reservoir water to induce the removal of the sediment plug at the mouth of the Santa Ana River would be necessary. Based on a unit cost of placed concrete of $100 per cu yd, the estimated order-of-magnitude for installing such a hydraulic structure in this vicinity is $1.2 million, including allowances for necessary dewatering or cofferdam construction. Because of the uncertainties regarding the availability of upstream water for flushing purposes, the probability of success of this type of structure in this location can only be regarded as low.

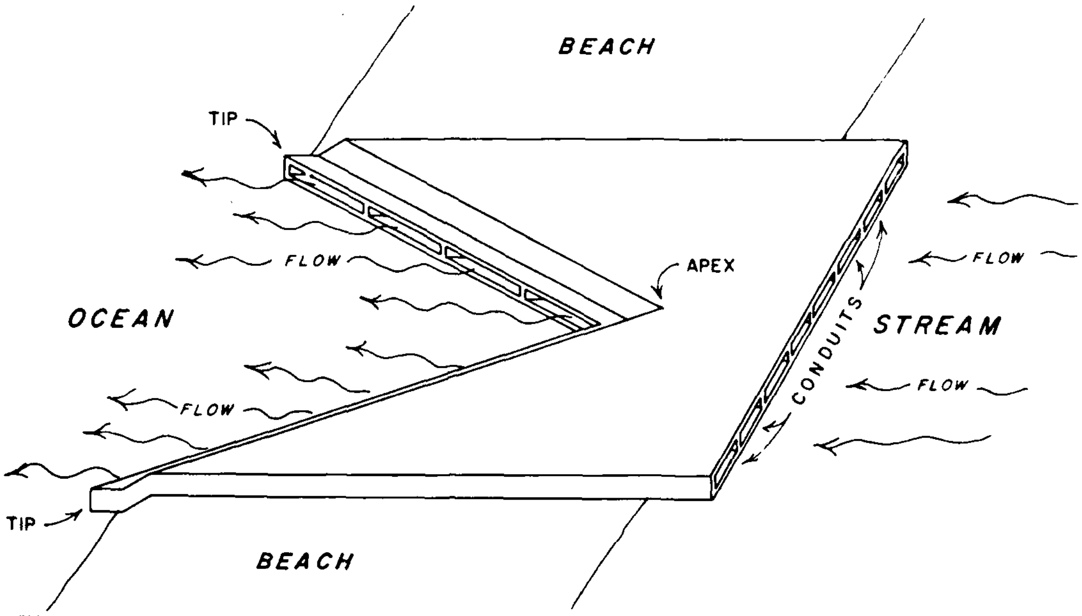

Figure 38. Conceptual model of Soil Conservation Service hydraulic structure for automatically removing sediment plug

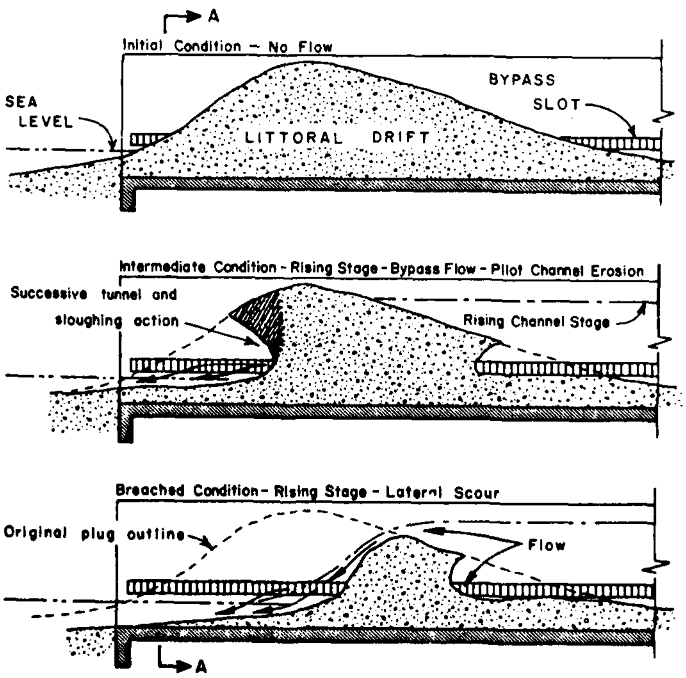

Figure 39. Theory of operation of Soil Conservation Service structure (after Nishimura and Lau 1979b)

PART VII: SUMMARY AND CONCLUSIONS

120. Two separate but interrelated problems exist along the section of southern California coastline between Anaheim Bay and Newport Bay. These include: (a) erosion of the beach immediately east of Anaheim Bay (Surfside-Sunset Beach), and (b) determination of the optimum location and temporal distribution of one million (1,000,000) cu yd of material suitable for beach nourishment that will be excavated during the deepening and widening of the Santa Ana River flood-control channel. Two additional closely aligned tasks should also be considered: (c) hydraulic design of a tidal flow system to allow for the flooding and emptying of a marsh habitat development area immediately north of the Pacific Coast Highway (on the east side of the Santa Ana River), and (d) development of design feasibility concepts for maintaining an opening at the mouth of the Santa Ana River to allow passage of tidal flow up the river to the habitat area. Complete closure of the exit of the river now occurs as littoral material is trapped between the jetties, particularly during the summer months when riverflow is minimal. The habitat development area is being planned to mitigate the loss of wildlife habitat resulting from the proposed widening of the Santa Ana River (8 acres), and for preservation in response to the mandate of the Endangered Species Act (84 acres). The utilization of as much of the excavation material as possible for beach nourishment purposes is highly desirable.

121. The temporal distribution of potential longshore transport of littoral material in the surf zone along this region of coastline was determined. Because of the large extent of coastline involved (approximately 17 miles), it was convenient to separate the region into three logical units, based on general shoreline orientation. Reach one extended from Anaheim Bay to Huntington Beach (including Surfside-Sunset Beach). The second reach extended from Huntington Beach to the Newport Submarine Canyon. The final reach extended south beyond the Newport Submarine Canyon for approximately 5 miles to Abalone Point.

122. It was determined that because of the sheltering effects of

the offshore islands, the general orientation of the coastline, the large shoal region in front of San Pedro Bay, and the nearness of the Newport Submarine Canyon to the shoreline, significant variations in littoral drift occur with distance along the coast of this region. Section one is experiencing a net southerly drift of approximately 276,000 cu yd per year; section two is believed to be losing approximately 112,000 cu yd per year in a southerly direction; and section three (beyond the submarine canyon and effectively out of the system) is experiencing a net southerly movement of approximately 127,000 cu yd per year. Apparently the Huntington Beach region will continue to be nourished naturally as long as the feeder beach at Surfside-Sunset Beach is maintained.

123. The wide beach immediately to the west of the Santa Ana River should not be adversely affected by the extension of the impermeable river jetties into the surf zone for the purpose of preventing the accumulation of littoral drift material in the mouth of the river. The potential jetty extensions would also provide a cell for the placement of a large portion of the material to be excavated from the flood channel (between the east jetty extension and the westernmost groin of the Newport Beach groin field). Significant amounts of additional material appear to be passing this stable groin field. Placement of fill material on the Huntington Beach area does not appear to be warranted from a beach nourishment standpoint. As long as the feeder beach at Surfside-Sunset Beach is maintained, the Huntington Beach region should remain a stable beach. This does not preclude the use of the Huntington Beach region as a depository for the disposal of acceptable excavated material. In the absence of jetty extensions, however, any material placed on the west side of the Santa Ana River will eventually migrate past the river mouth and contribute to the blockage problem. The excavated material could be effectively applied to the Surfside-Sunset Beach area, except for the fact that transportation costs will probably be prohibitive.

124. The beaches on the east side of Santa Ana River are receiving nourishment from the area west of the river at the present time; however, the material is apparently passing along the surf zone since the groin

field on the east side of the river appears to be maintaining a stabilized section of beach. Hence, the material presently passing the river mouth is being transferred unimpeded downcoast past the groin field, and the City of Newport Beach has indicated that the City is satisfied with the present beach configuration. However, significant capacity exists for the placement of a large quantity of beach fill material to be excavated by widening and deepening the Santa Ana River lower section. Up to 650,000 cu yd of material could be placed in the existing groin field, and an additional 350,000 cu yd could be placed between the Newport Beach west groin and the Santa Ana River proposed east jetty extension. The groin field commences approximately 4,500 ft east of the east river jetty.

125. It was determined by Keulegan's approximation, and confirmed by one-dimensional numerical techniques, that a variety of concrete gated pipes and culverts could be installed that would effectively transmit approximately 98 percent of the tidal prism necessary to induce maximum bay water-surface elevation in the proposed habitat development area. This requirement was dictated by the necessity to ensure a precise bay water-surface rise and fall with the lunar ocean tide of the region.

126. The Santa Ana River mouth region experiences a significant amount of gross transport during the summer months of July through October, which is also a time of low (or no) flow of water down the Santa Ana River. Hence, the capability of the river to flush littoral material from the river mouth is minimal. If tidal exchange is required through the river mouth, then some kind of operational and/or structural measures must be developed to ensure this capability. Feasibility conceptual alternatives for providing unrestricted tidal exchange through the mouth of the Santa Ana River were considered, their probability of success was qualitatively deduced, and an order-of-magnitude estimate of their installation cost was approximated. These potential concepts are summarized as follows:

Concept	Order-of-Magnitude Cost Estimate Millions of $	Estimated Probability of Successful Operation
Jetty extensions	$2.2	Moderate to high
Dragline method	0.3	Low
Dragline plus auxiliary wall	0.9	Low to moderate
Floodgates	3.5	Low to moderate
Floodgates plus auxiliary wall	4.1	Low to moderate
Pipeline	4.0	Low
Jet pump sand bypassing system	3.0	Low to moderate
Hydraulic structure	1.2	Low

The viability of these (and other) concepts can be determined only by detailed design studies and economic evaluations. Results of a physical model study would provide guidance for the solution of many of the problems existing in the vicinity of the Santa Ana River mouth.

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Table 1

Summary of Beach Nourishment Activities*

Surfside-Sunset Beach to Newport Beach, California

	Year	Amount, cu yd	Source	Disposal Area
	1935	3,700,000	In Newport Harbor	Newport Beach
	1935	1,900,000	In Newport Harbor	46th St. to Pier
	1945	202,000	Seal Beach Channel	Surfside Beach
	1947	1,220,000	Seal Beach Harbor	Surfside Beach
	1956	874,000	Seal Beach Harbor	Surfside Beach
Stage 1	1964	4,000,000	Seal Beach Harbor	Surfside Beach
Stage 1	1964	1,315,000	Seal Beach Channel	Surfside Beach
	1965	124,000	Balboa Beach	36th to 47th St.
	1966	60,000	Balboa Beach	36th to 47th St.
	1967	150,000	Balboa Beach	36th to 47th St.
Stage 2	1968	494,000	8th St. to Ent. Ch. Newport Beach	32nd to 50th St. Newport Beach
Stage 2	1968	246,000	56th St. to Santa Ana River	40th to 46th St. Newport Beach
Stage 3	1969	750,000	Santa Ana River to Lugonia St.	40th to 46th St. Newport Beach
Stage 3	1970	124,000	Santa Ana River Channel	31st to 36st St. Newport Beach
Stage 4	1971	2,260,000	Seal Beach Harbor	Surfside Beach
Stage 5	1973	358,000	Santa Ana River Channel mouth	28th to 48th St. Newport Beach
Stage 7	1979	1,644 000	Offshore Borrow Area	Surfside Beach

Note: Stage 6, the offshore breakwater, has been deferred until a definite need and precise location have been established.

* Source: Personal communication from Mr. Tad Nizinski, U. S. Army Engineer District, Los Angeles, February 1980.

Table 2

Summary of Potential Longshore Transport Computations

Surfside-Sunset Beach, California

(All Values in cu yd)

	Sea		Northern Swell		Southern Swell		Sum		Net		
Month	+ North	- South	+ North	- South	+ North	- South	+ North	- South	+ North	- South	Gross
Jan	14,679	19,344	0	88,622	0	0	14,679	107,966		93,287	122,645
Feb	74,196	13,077	0	203,822	0	0	74,196	216,899		142,703	291,095
Mar	29,891	24,830	0	57,258	0	0	29,891	82,088		52,197	111,979
Apr	4,865	20,603	0	55,700	0	0	4,865	76,303		71,438	81,168
May	2,086	14,595	0	13,268	20,497	0	22,583	27,863		5,280	50,446
Jun	2,603	12,398	0	3,102	13,202	0	15,805	15,500	305		31,305
Jul	4,242	12,692	3,039	0	37,165	0	44,446	12,692	31,754		57,138
Aug	2,550	10,700	3,897	0	36,760	0	43,207	10,700	32,507		53,907
Sep	1,054	10,460	8,975	577	28,384	0	38,413	11,037	27,376		49,450
Oct	4,711	5,887	2,007	16,569	21,580	0	28,298	22,456	5,842		50,754
Nov	1,112	10,547	0	2,410	0	0	1,112	12,957		11,845	14,069
Dec	27,367	7,495	0	16,985	0	0	27,367	24,480	2,887		51,847
Annual	169,356	162,628	17,918	458,313	157,588	0	344,862	620,941	100,671	376,750	965,803
Net	6,728			440,395	157,588			276,079		276,079	

Table 3

Summary of Potential Longshore Transport Computations

Santa Ana River Mouth Region, California

(All Values in cu yd)

	Sea		Northern Swell		Southern Swell		Sum		Net		
Month	+ North	- South	+ North	- South	+ North	- South	+ North	- South	+ North	- South	Gross
Jan	11,682	28,159	0	68,230	0	0	11,682	96,389		84,707	108,071
Feb	66,681	24,159	0	151,881	0	0	66,681	176,040		109,359	242,721
Mar	24,463	38,523	0	47,827	0	0	24,463	86,350		61,887	110,813
Apr	3,445	29,085	0	48,424	0	0	3,445	77,509		74,064	80,954
May	1,557	22,567	0	10,517	39,604	0	41,161	33,084	8,077		74,245
Jun	1,720	16,882	0	2,938	19,429	0	21,149	19,820	1,329		40,969
Jul	3,681	17,752	5,237	0	84,507	0	93,425	17,752	75,673		111,177
Aug	2,083	16,182	6,498	0	68,904	0	77,485	16,182	61,303		93,667
Sep	958	16,625	15,438	570	53,077	0	69,473	17,195	52,278		86,668
Oct	3,810	11,181	3,421	14,168	56,780	0	64,011	25,349	38,662		89,360
Nov	902	14,446	0	2,070	0	0	902	16,516		15,614	17,418
Dec	23,220	12,848	0	14,010	0	0	23,220	26,858		3,638	50,078
Annual	144,202	248,409	30,594	360,635	322,301	0	497,097	609,044	237,322	349,269	1,106,141
Net		104,207		330,041	322,301			111,947		111,947	

Table 4

Summary of Potential Longshore Transport Computations

Newport Beach, California

(All Values in cu yd)

Month	Sea		Northern Swell		Southern Swell		Sum		Net		Gross
	+ North	- South	+ North	- South	+ North	- South	+ North	- South	+ North	- South	
Jan	9,001	18,721	0	80,054	0	0	9,001	98,775		89,774	107,776
Feb	47,807	14,493	0	175,872	0	0	47,807	190,365		142,558	238,172
Mar	15,963	26,015	0	45,977	0	0	15,963	71,992		56,029	87,955
Apr	2,607	17,847	0	38,997	0	0	2,607	56,844		54,237	59,451
May	1,284	13,405	0	10,751	36,121	0	37,405	24,156	13,249		61,561
Jun	1,322	11,408	0	2,250	18,694	0	20,016	13,658	6,358		33,674
Jul	2,817	10,960	3,791	0	69,588	0	76,196	10,960	65,236		87,156
Aug	1,774	9,101	6,166	0	58,248	0	66,188	9,101	57,087		75,289
Sep	882	9,142	12,983	355	49,309	0	63,174	9,497	53,677		72,671
Oct	3,729	6,036	2,398	11,653	46,817	0	52,944	17,689	35,255		70,633
Nov	750	9,119	0	2,111	0	0	750	11,230		10,480	11,980
Dec	16,932	8,998	0	13,060	0	0	16,932	22,058		5,126	38,990
Annual	104,868	155,245	25,338	381,080	278,777	0	408,983	536,325	230,862	358,204	945,308
Net		50,377		355,742	278,777			127,342		127,342	

APPENDIX A: EFFECT OF PERIOD, SHELTERED DEEPWATER WAVE HEIGHT, AND ANGLE OF APPROACH ON BREAKER HEIGHT

SURFSIDE-SUNSET BEACH REGION, CALIFORNIA

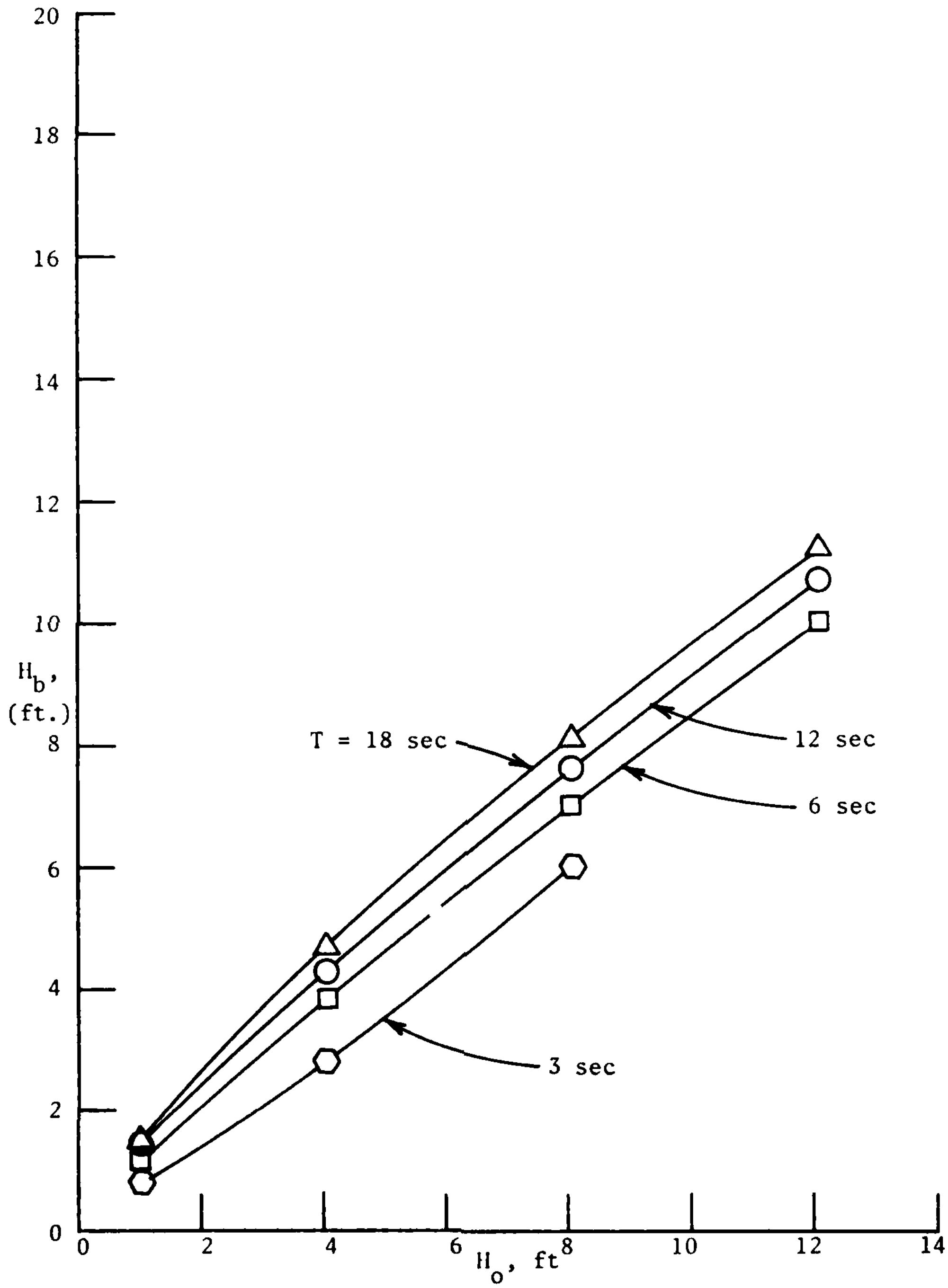

Figure A1. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Surfside-Sunset Beach region, Calif.
$\theta_{100} = 157°$

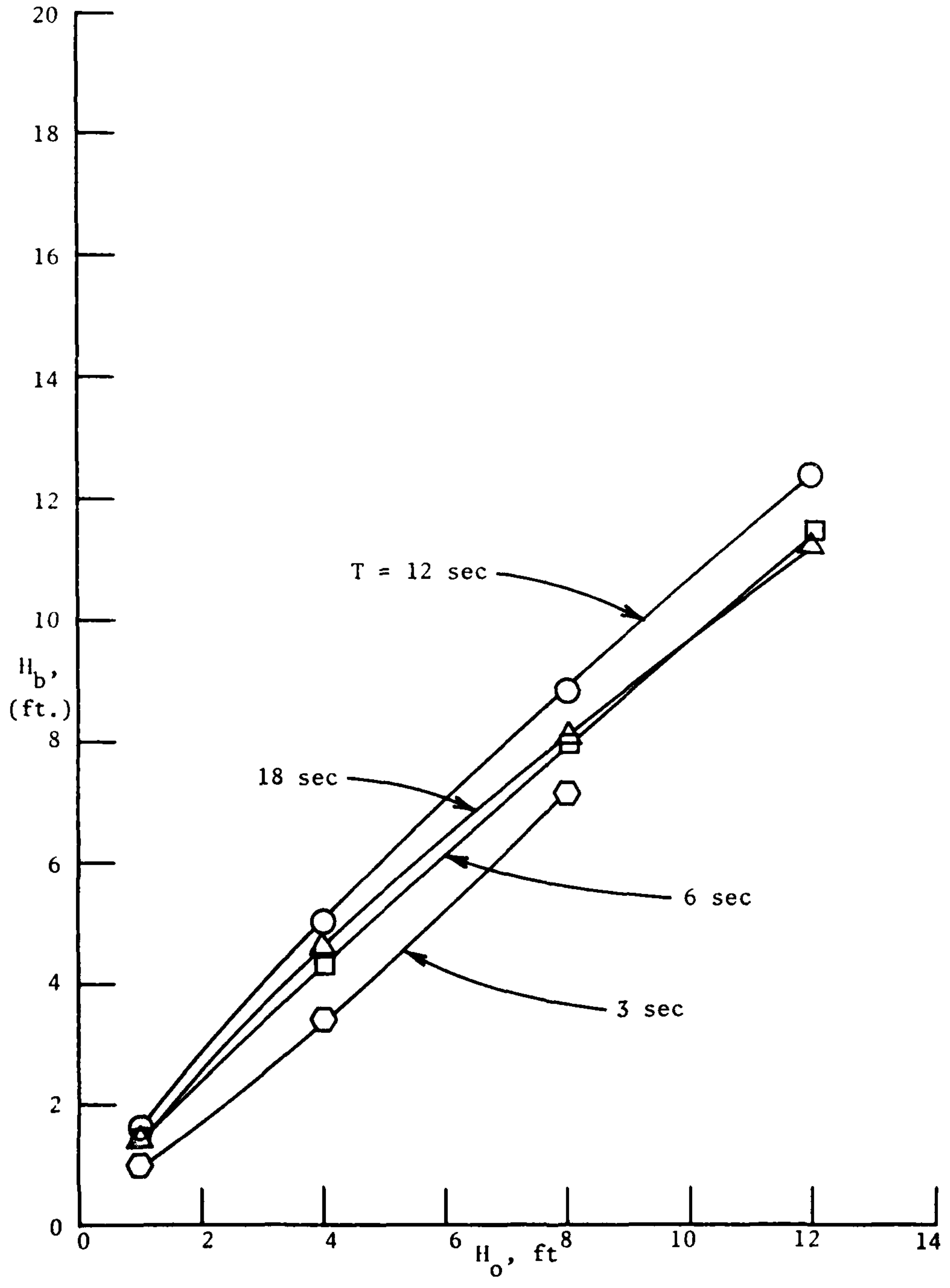

Figure A2. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Surfside-Sunset Beach region, Calif.

$\theta_{100} = 180°$

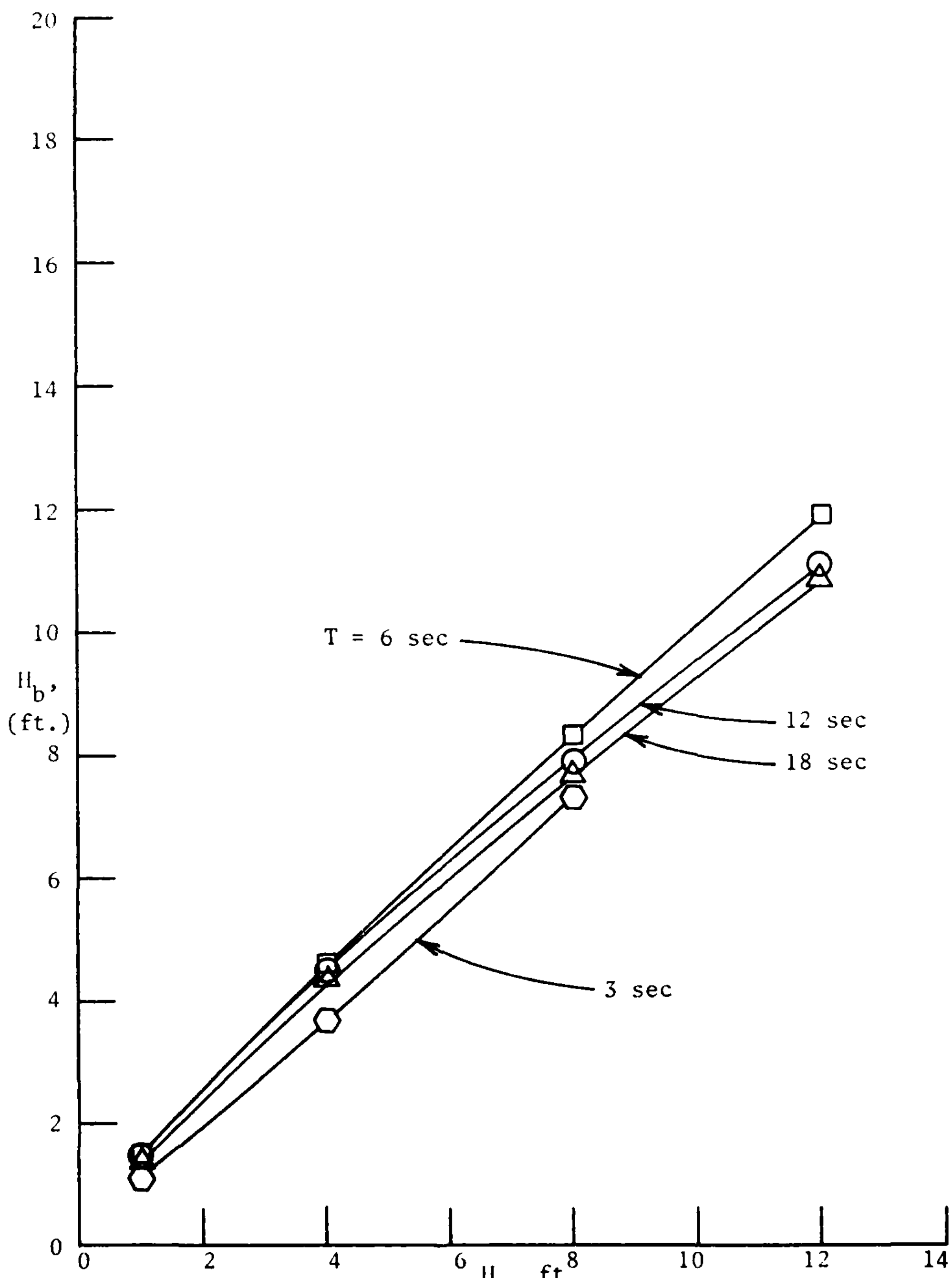

Figure A3. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Surfside-Sunset Beach region, Calif. $\theta_{100} = 202°$

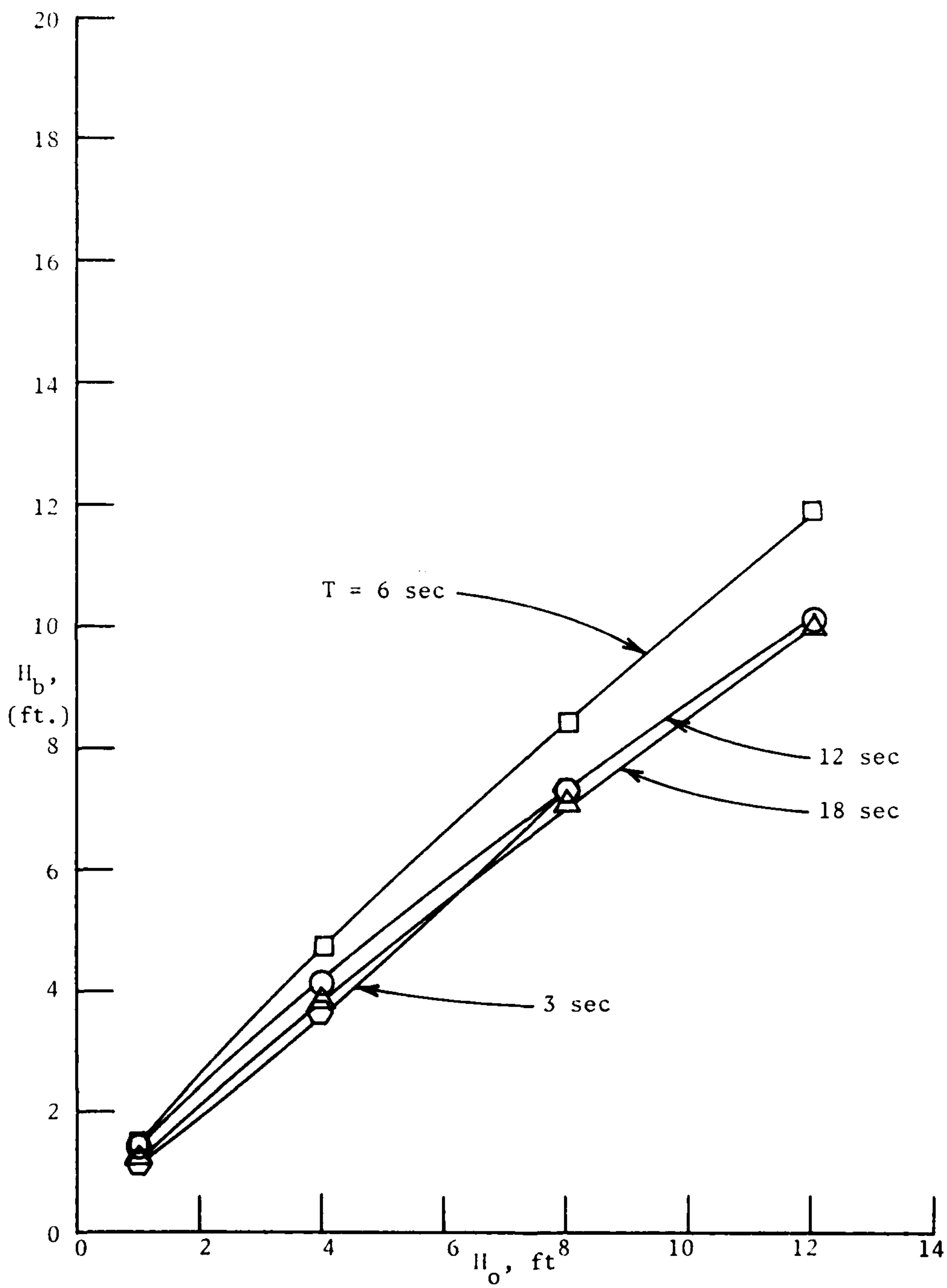

Figure A4. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Surfside-Sunset Beach region, Calif. $\theta_{100} = 225°$

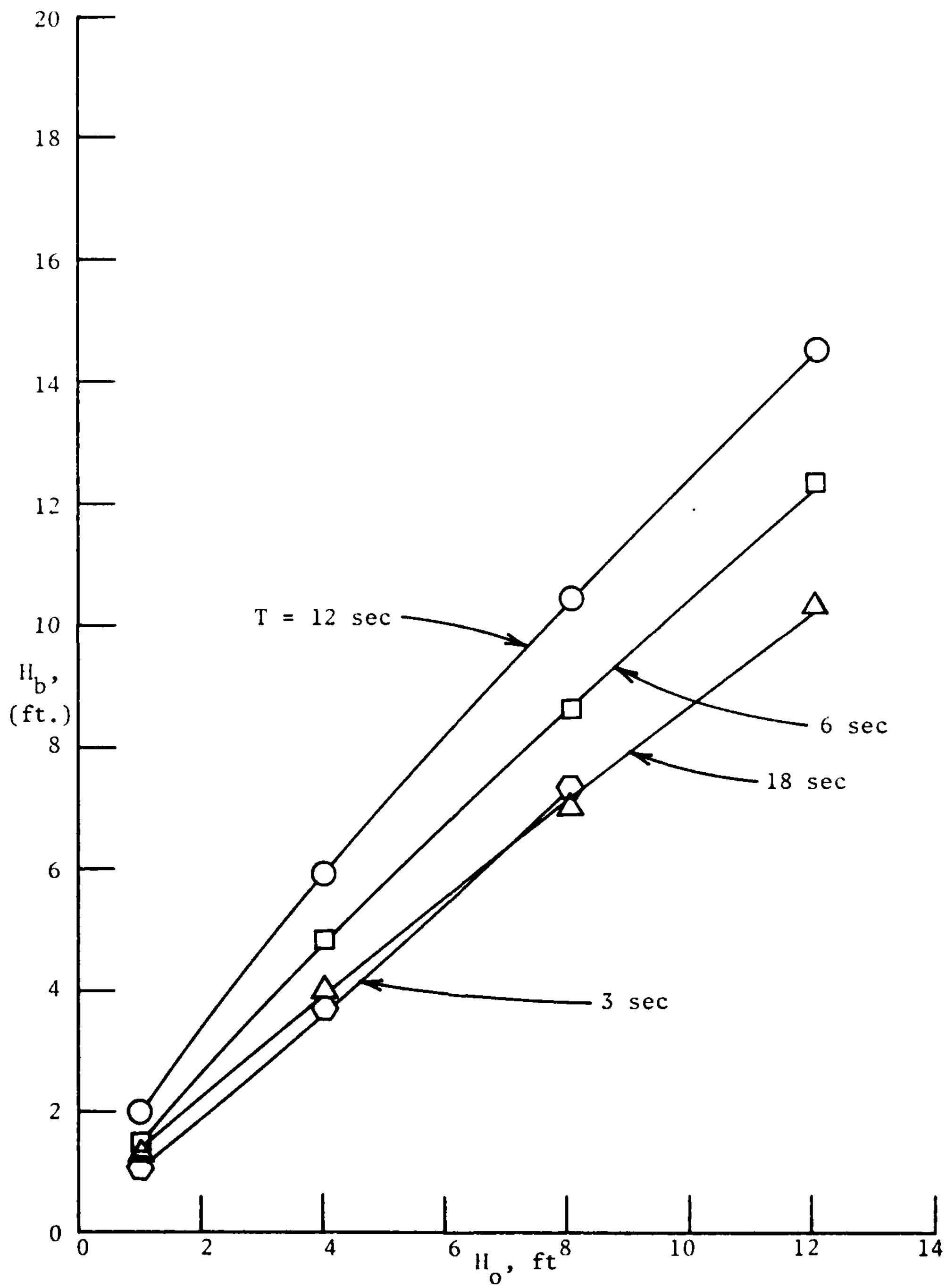

Figure A5. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Surfside-Sunset Beach region, Calif. $\theta_{100} = 247°$

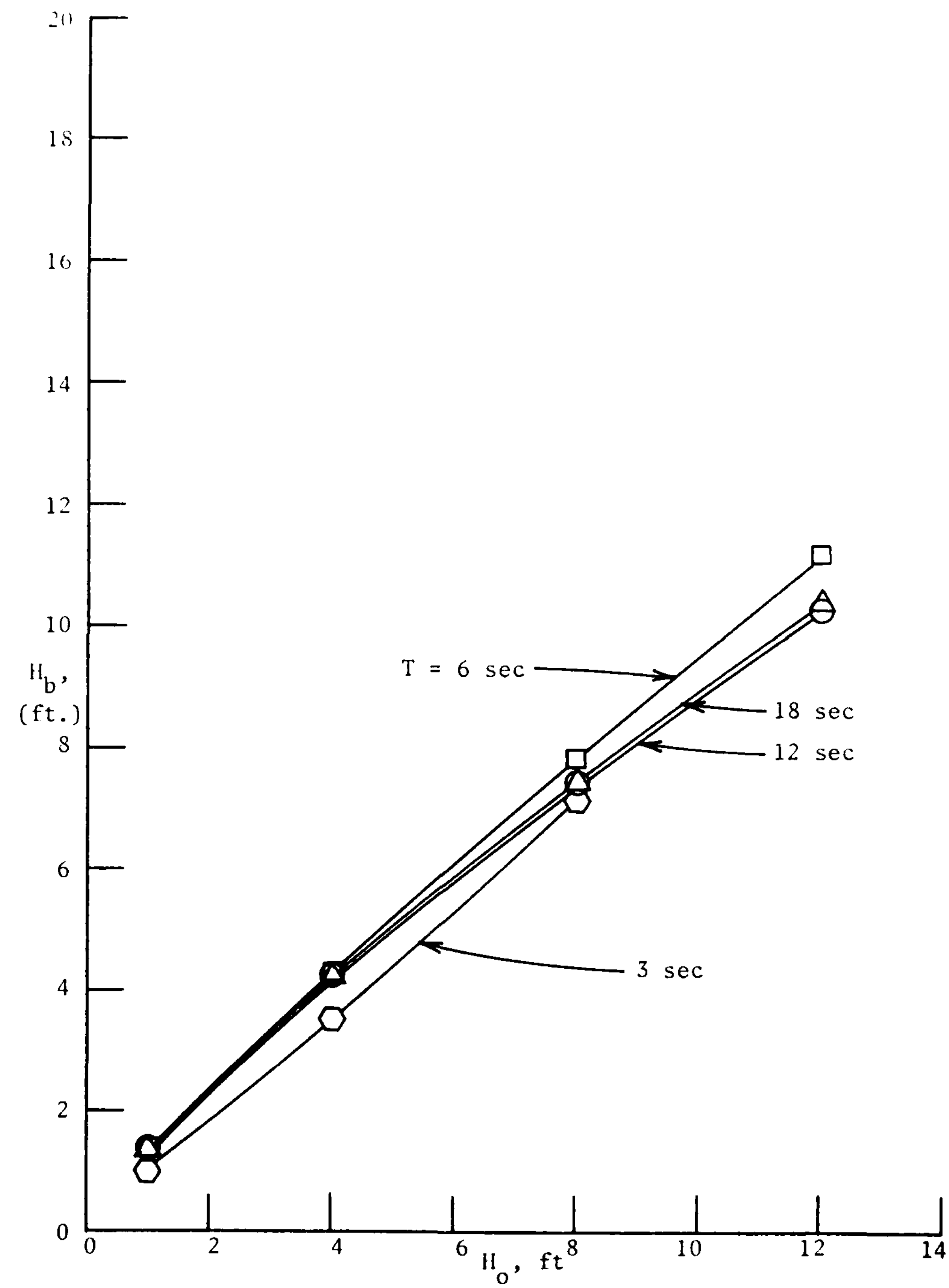

Figure A6. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Surfside-Sunset Beach region, Calif. $\theta_{100} = 270°$

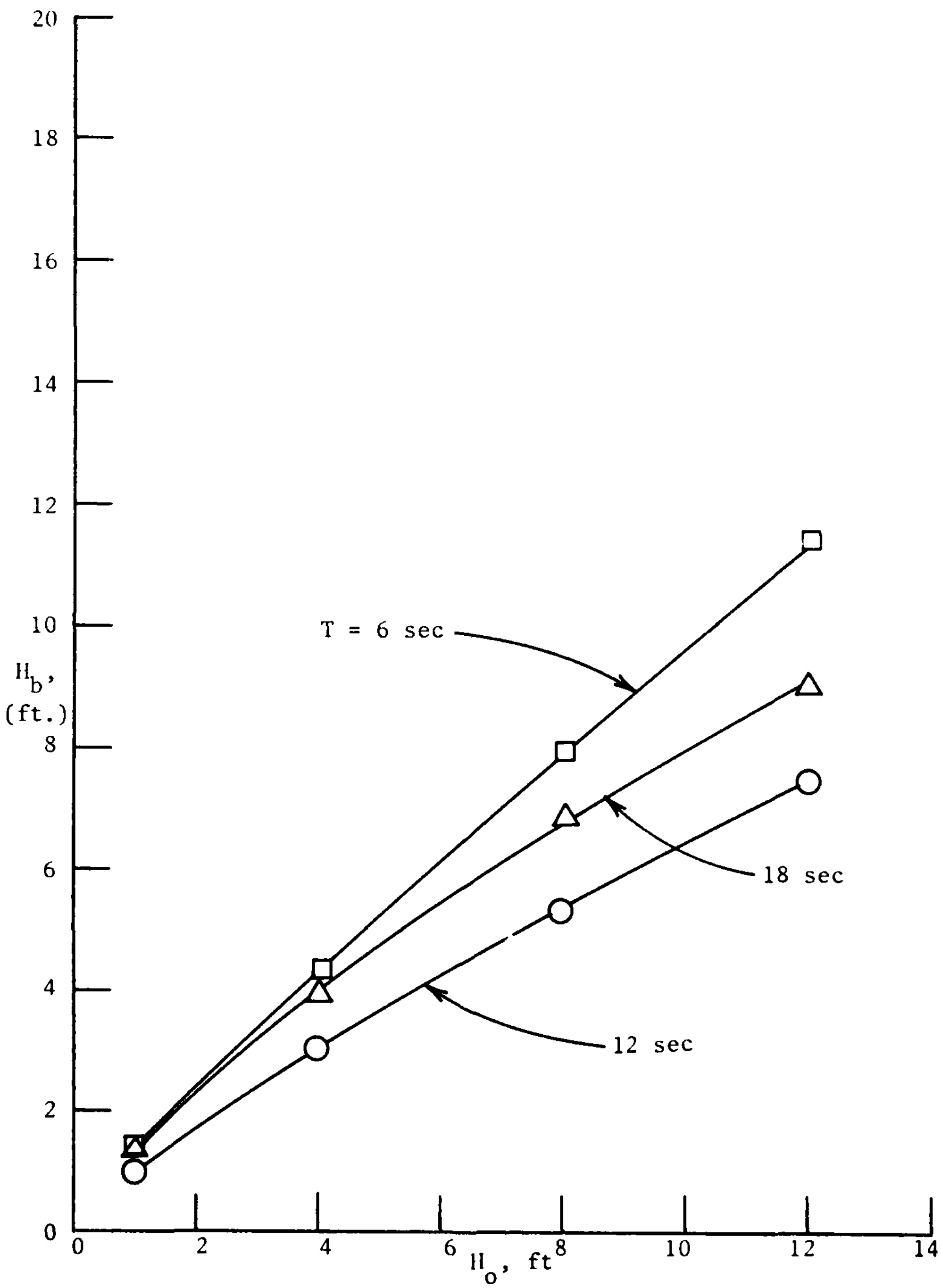

Figure A7. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Surfside-Sunset Beach region, Calif. $\theta_{100} = 292°$

APPENDIX B: EFFECT OF PERIOD, SHELTERED DEEPWATER WAVE HEIGHT, AND ANGLE OF APPROACH ON BREAKER HEIGHT

SANTA ANA RIVER MOUTH REGION, CALIFORNIA

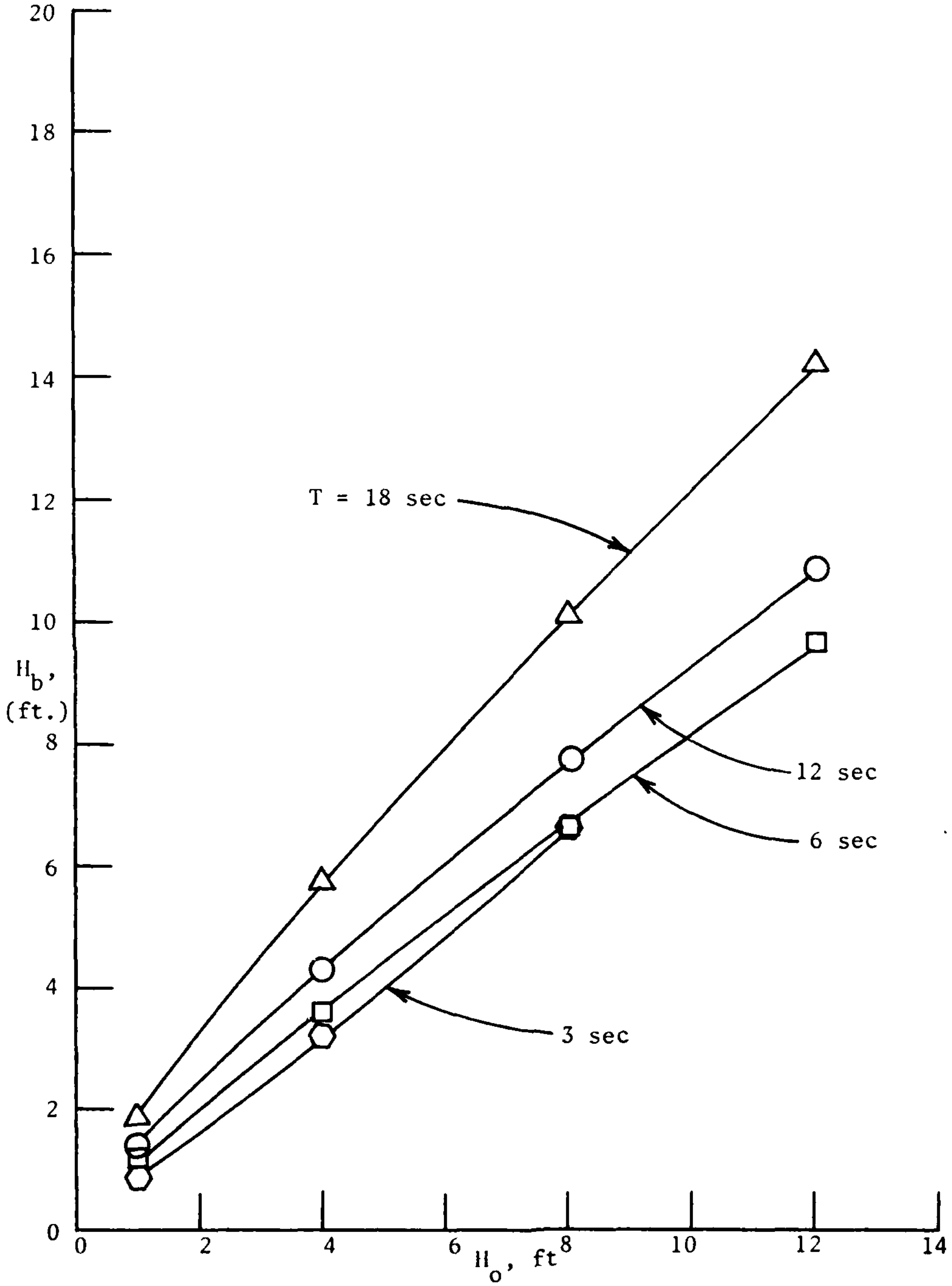

Figure B1. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Santa Ana River mouth region, Calif. $\theta_{100} = 157°$

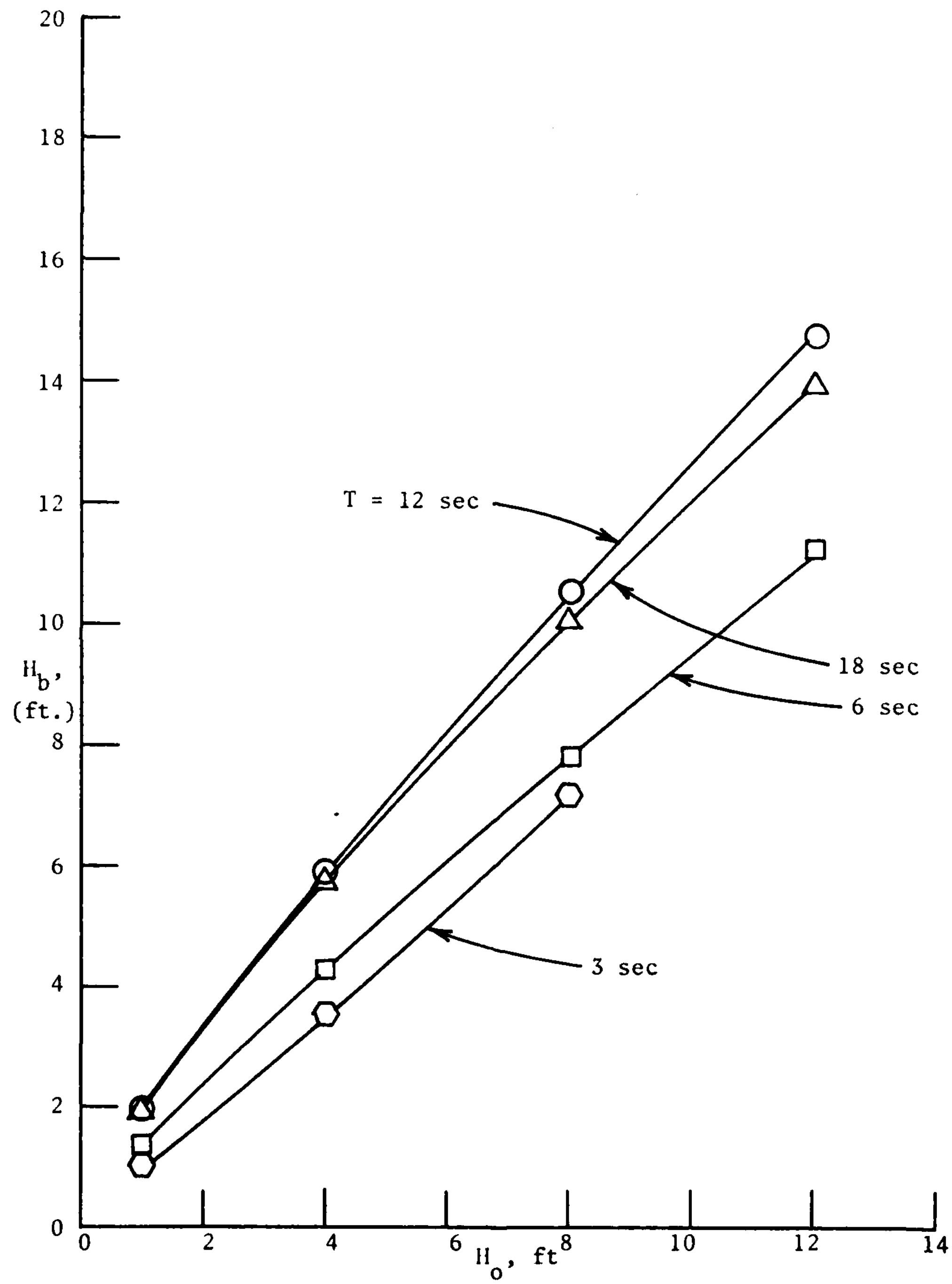

Figure B2. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Santa Ana River mouth region, Calif. $\theta_{100} = 180°$

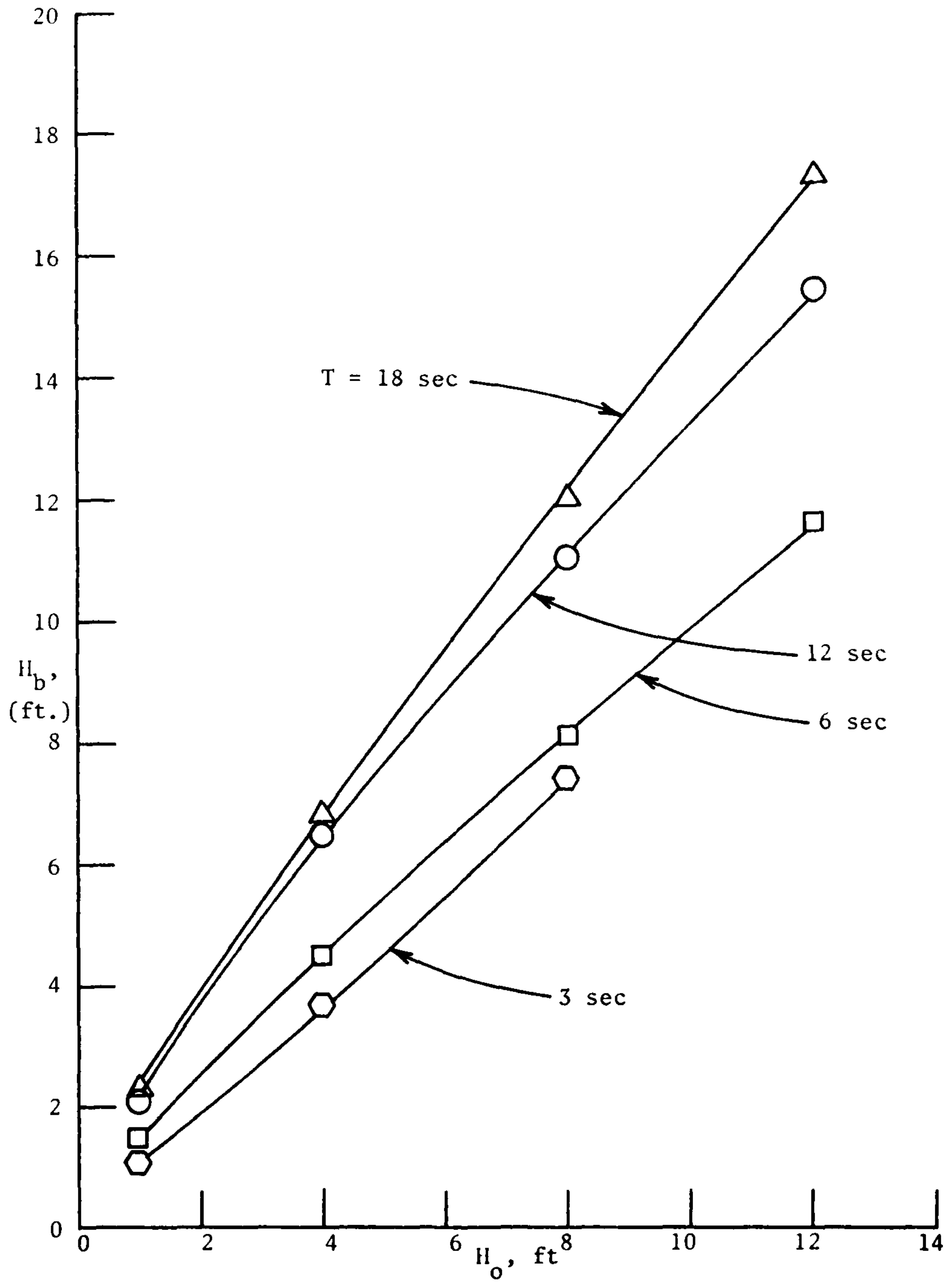

Figure B3. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Santa Ana River mouth region, Calif. $\theta_{100} = 202°$

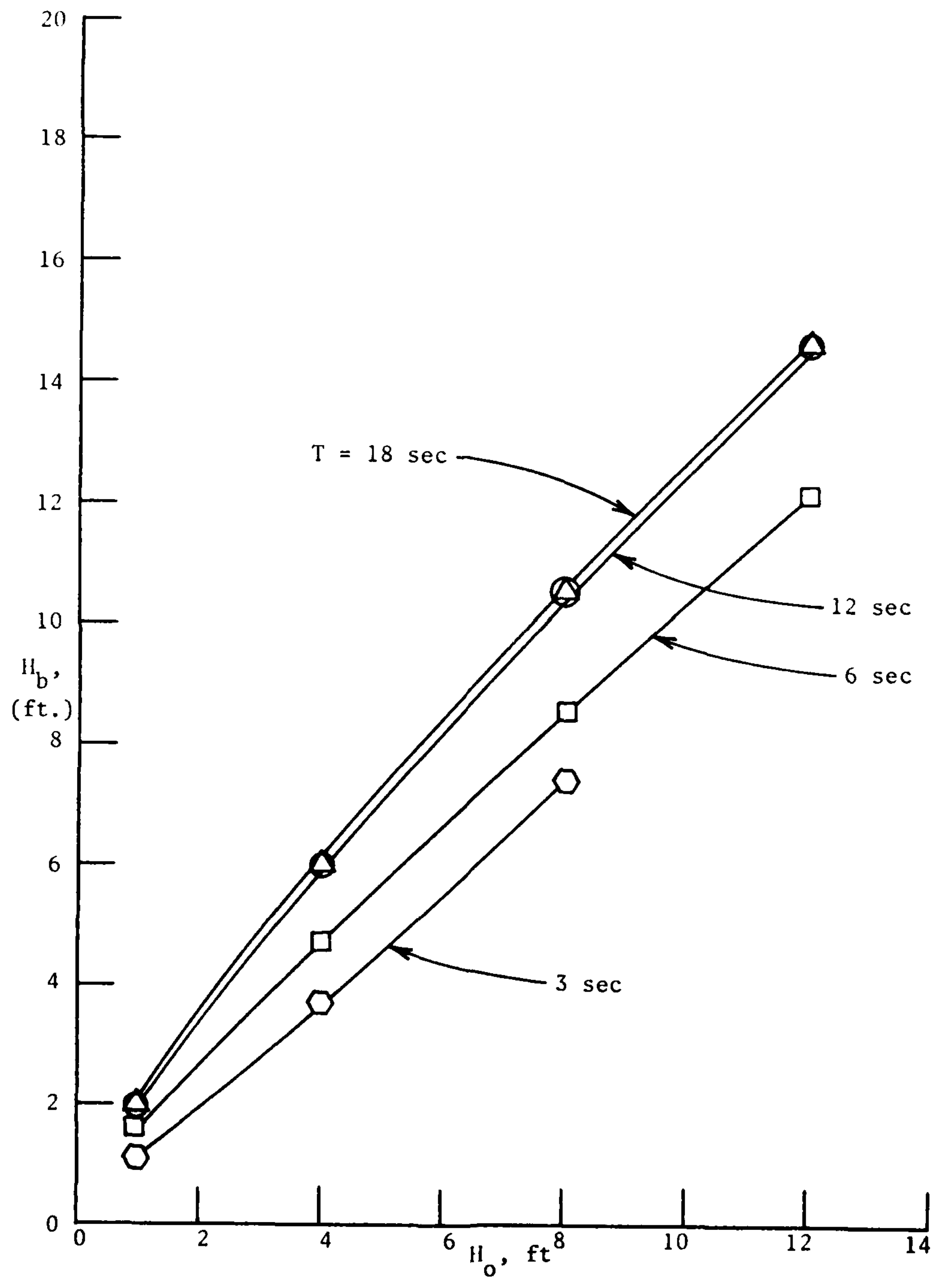

Figure B4. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Santa Ana River mouth region, Calif. $\theta_{100} = 225°$

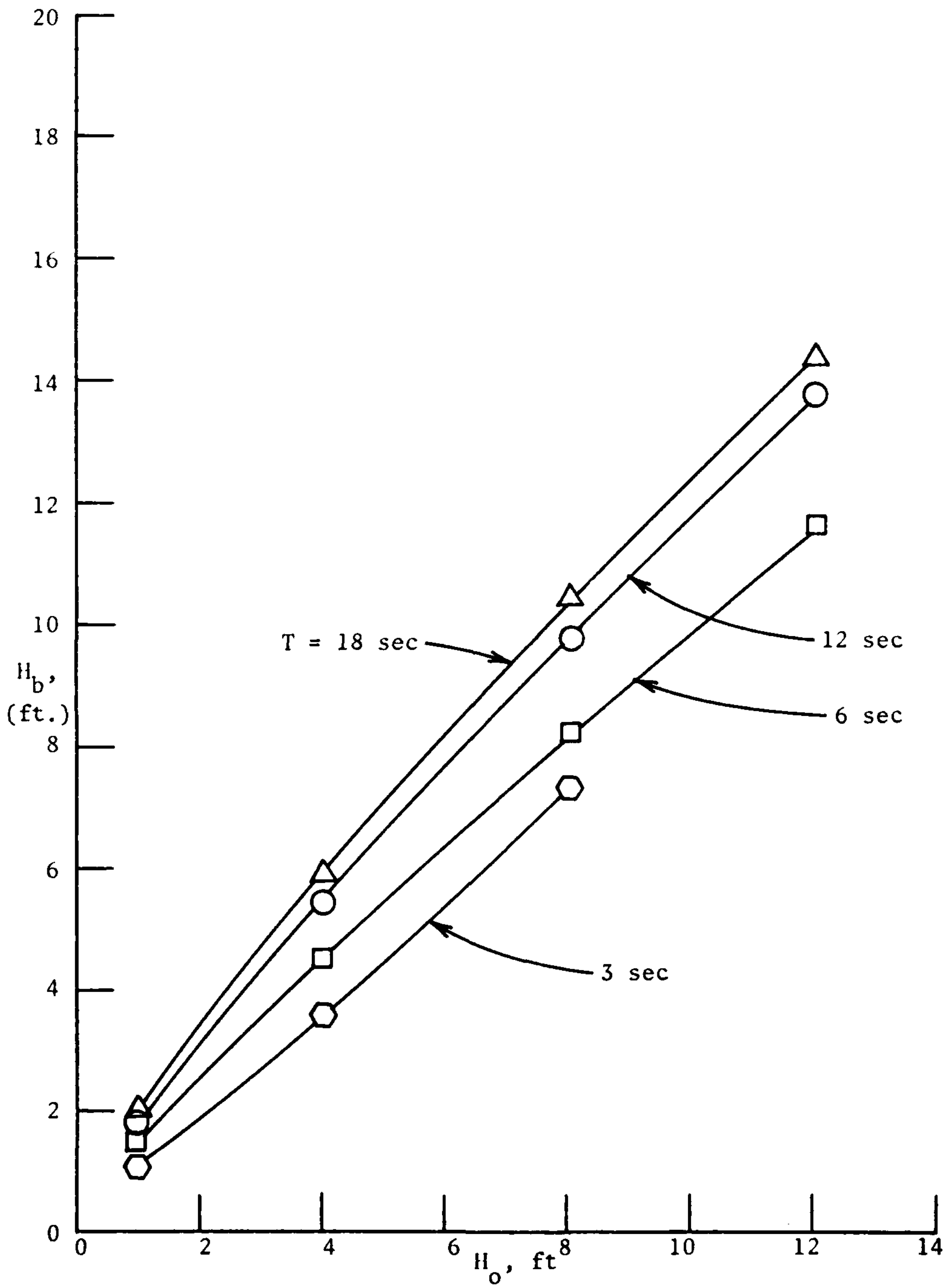

Figure B5. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Santa Ana River mouth region, Calif.
$\theta_{100} = 247°$

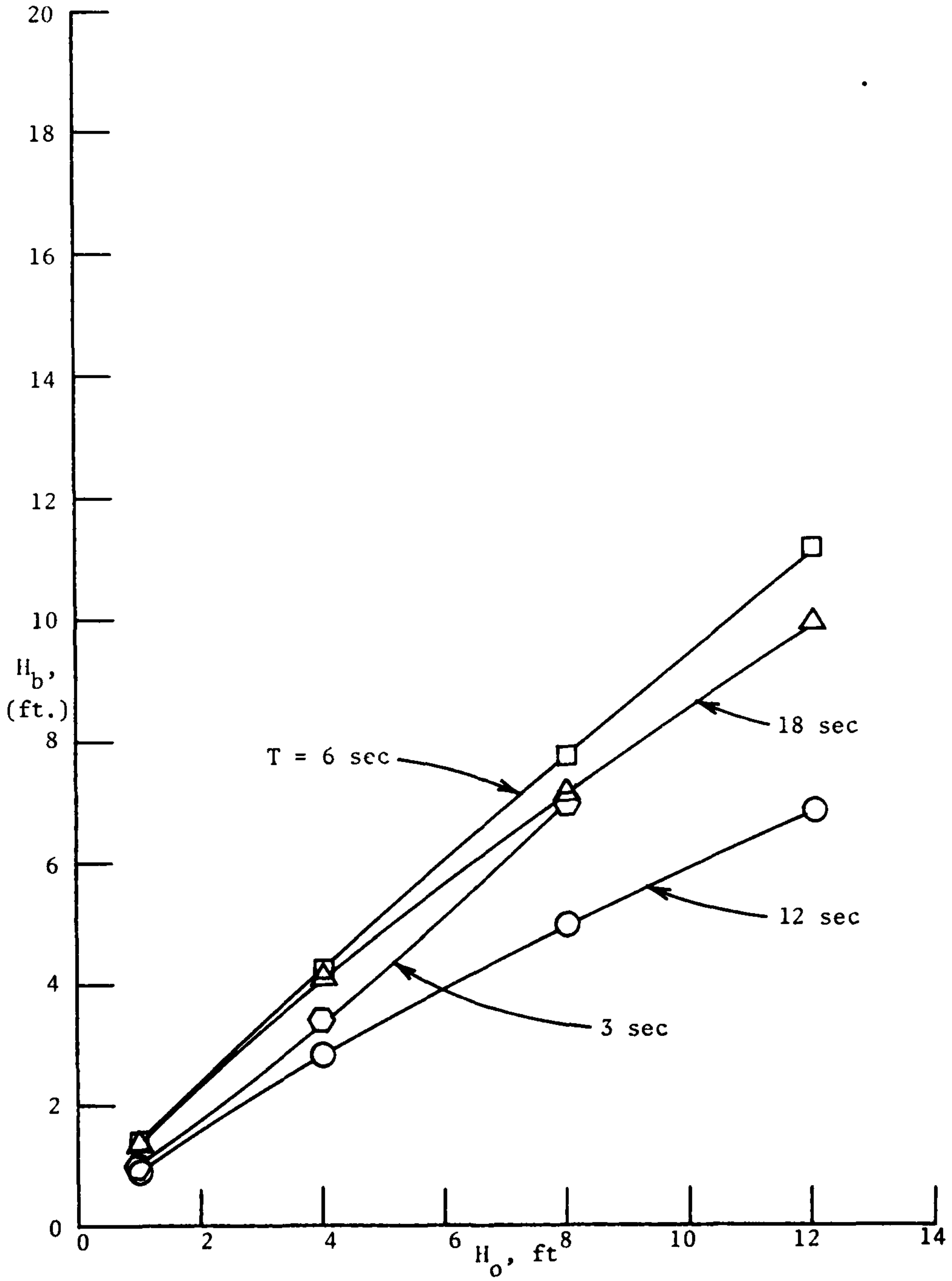

Figure B6. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Santa Ana River mouth region, Calif.
$\theta_{100} = 270°$

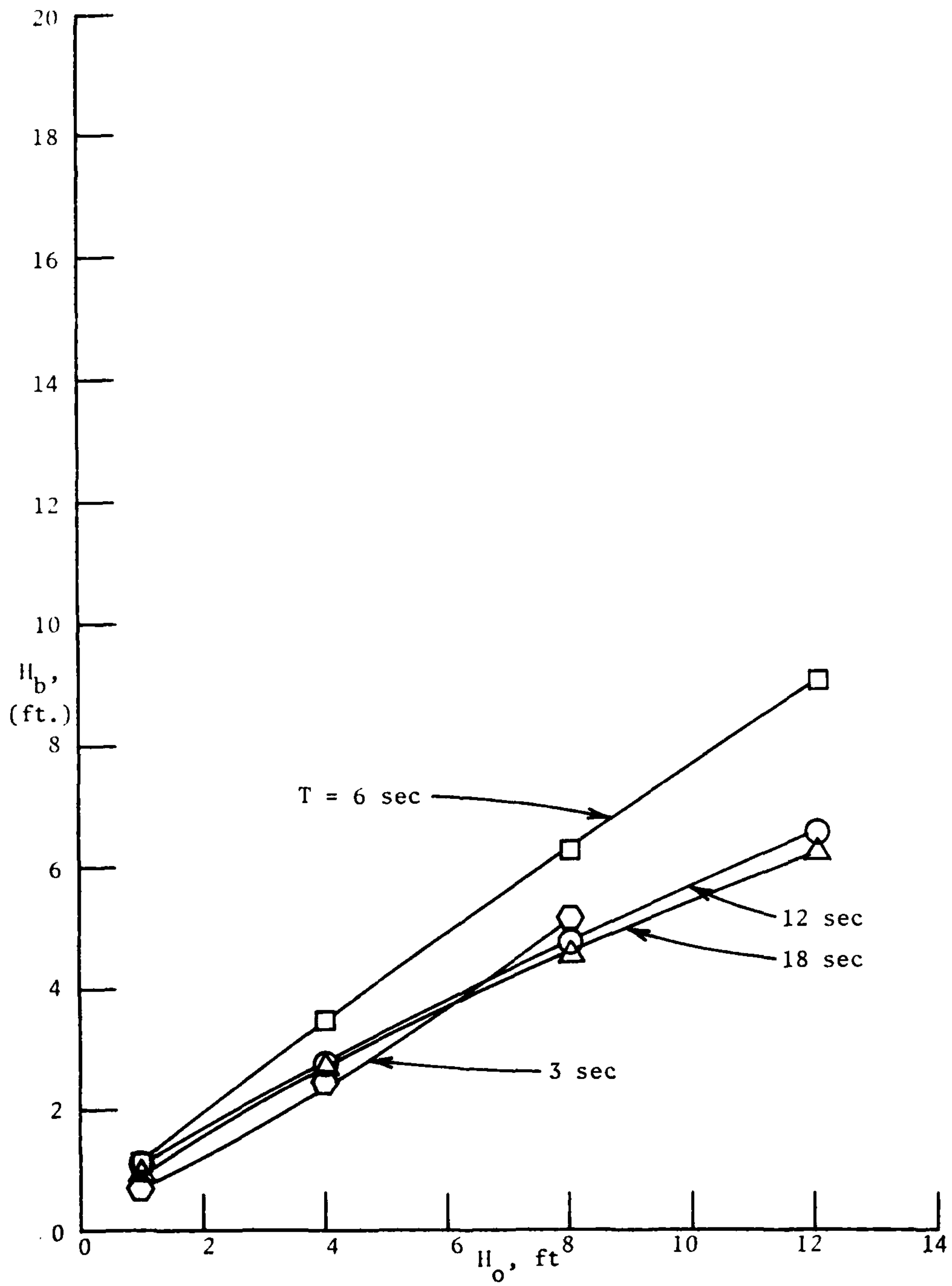

Figure B7. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Santa Ana River mouth region, Calif.

$\theta_{100} = 292°$

APPENDIX C: EFFECT OF PERIOD, SHELTERED DEEPWATER WAVE HEIGHT, AND ANGLE OF APPROACH ON BREAKER HEIGHT

<u>NEWPORT BEACH REGION, CALIFORNIA</u>

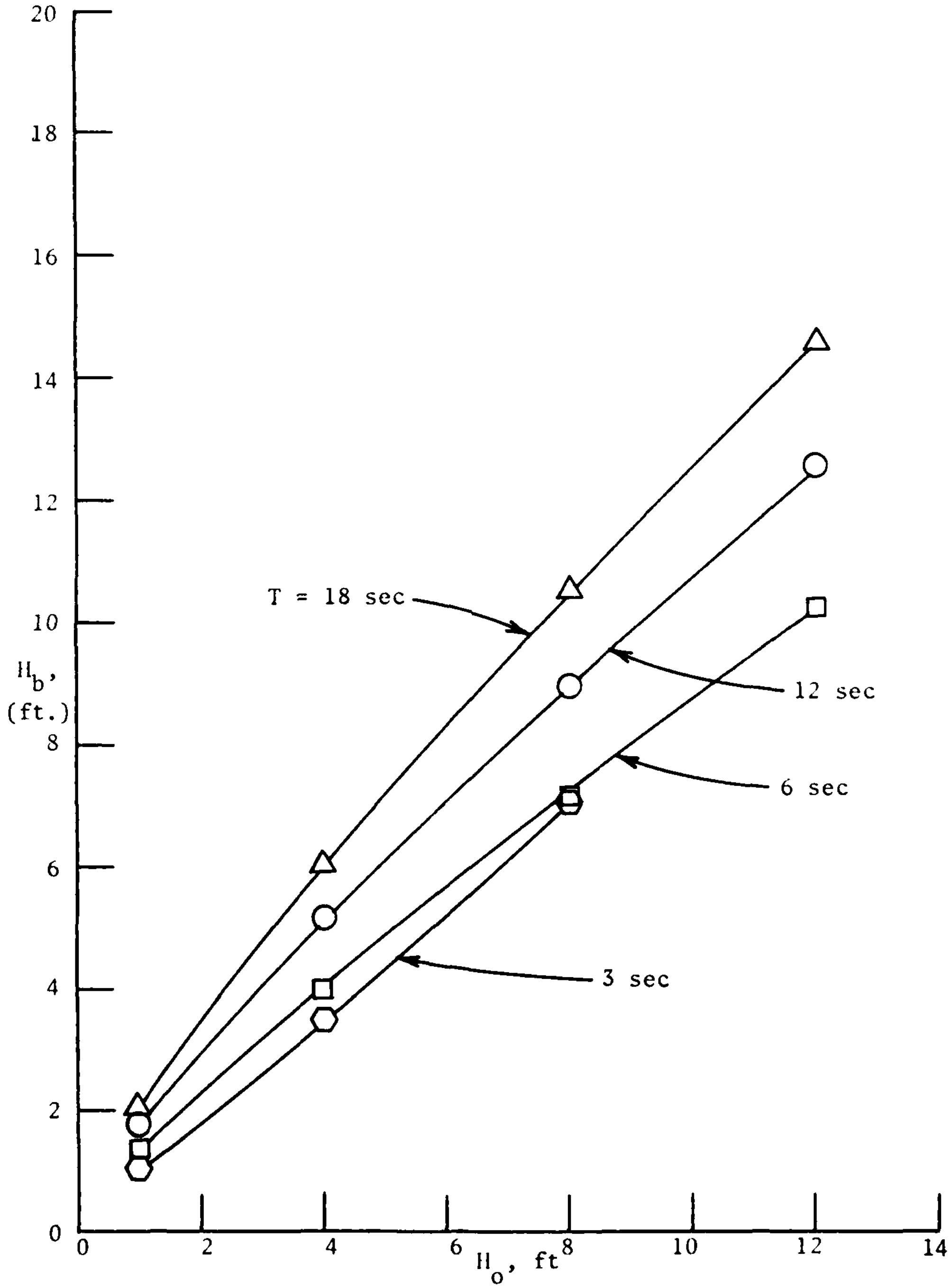

Figure C1. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Newport Beach region, Calif. $\theta_{100} = 157°$

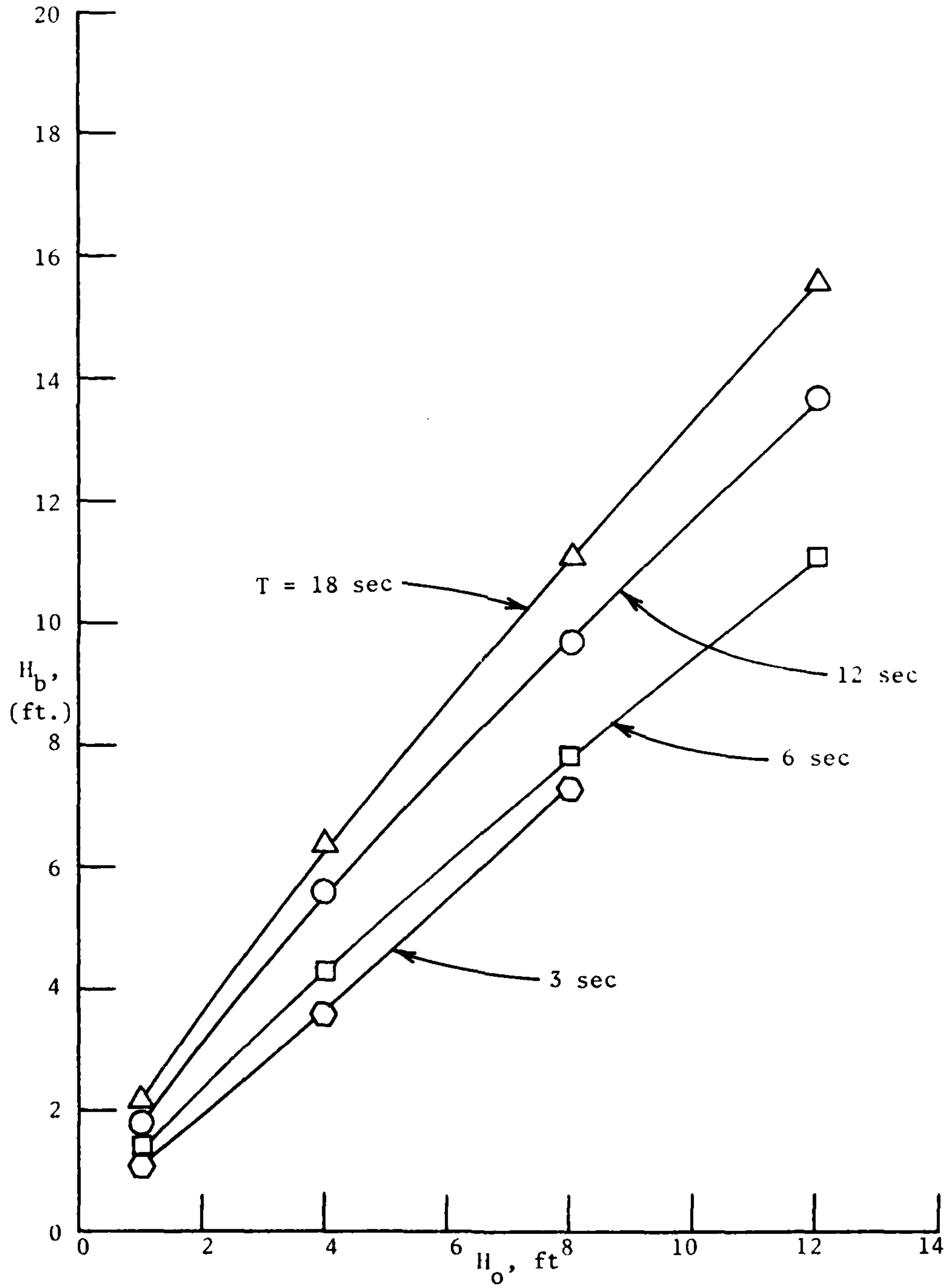

Figure C2. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Newport Beach region, Calif. $\theta_{100} = 180°$

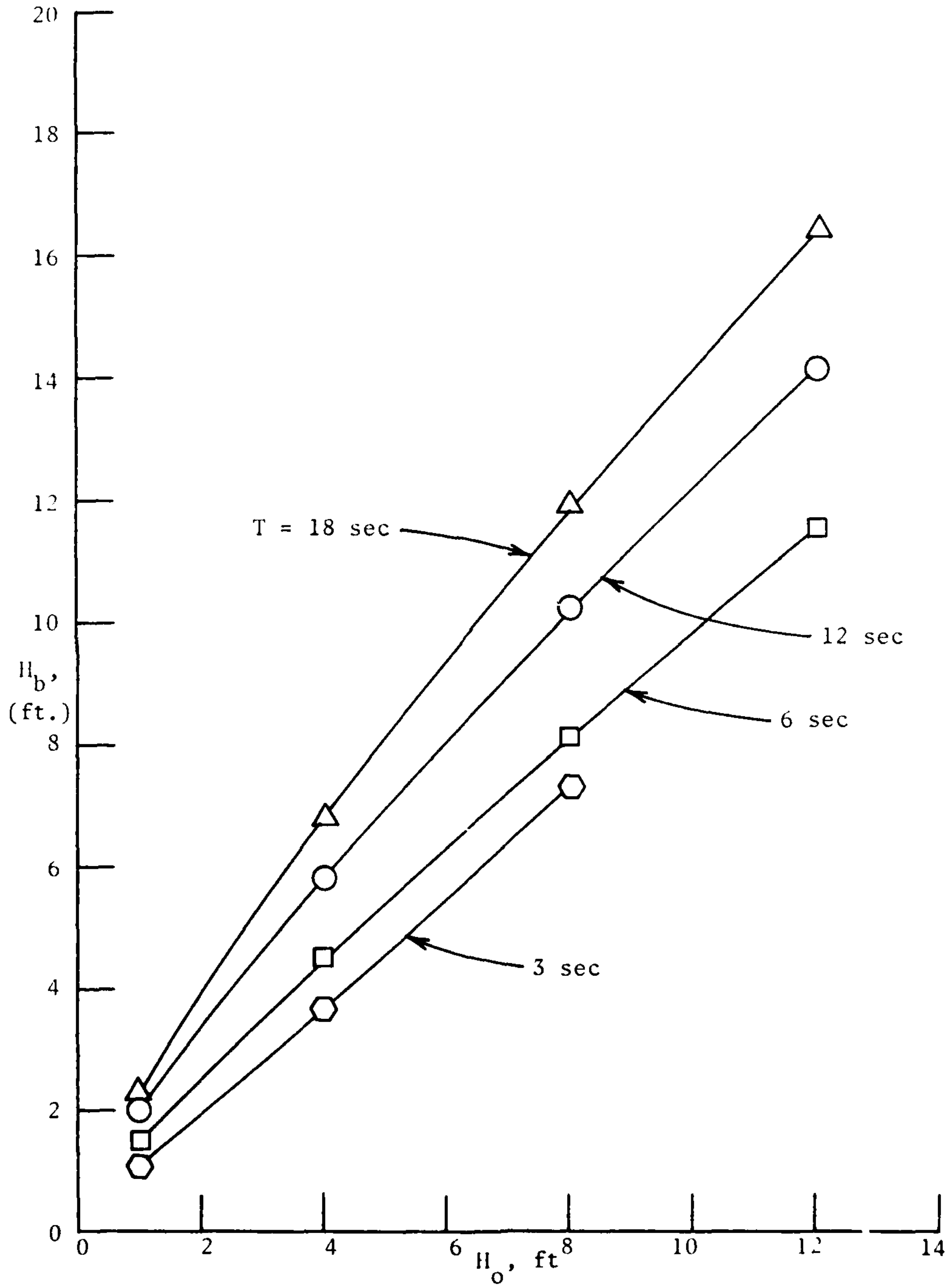

Figure C3. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Newport Beach region, Calif. $\theta_{100} = 202°$

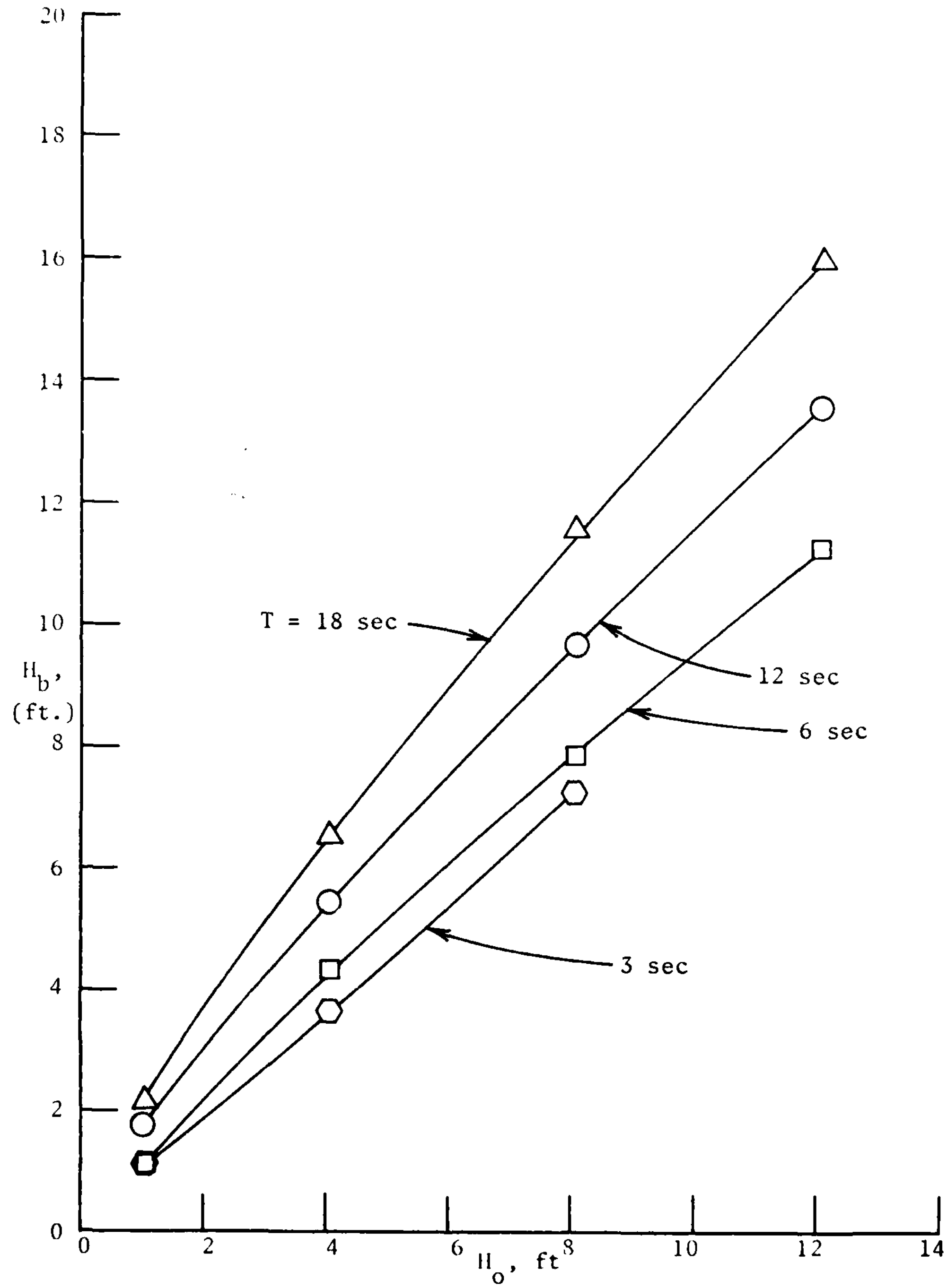

Figure C4. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Newport Beach region, Calif. $\theta_{100} = 225°$

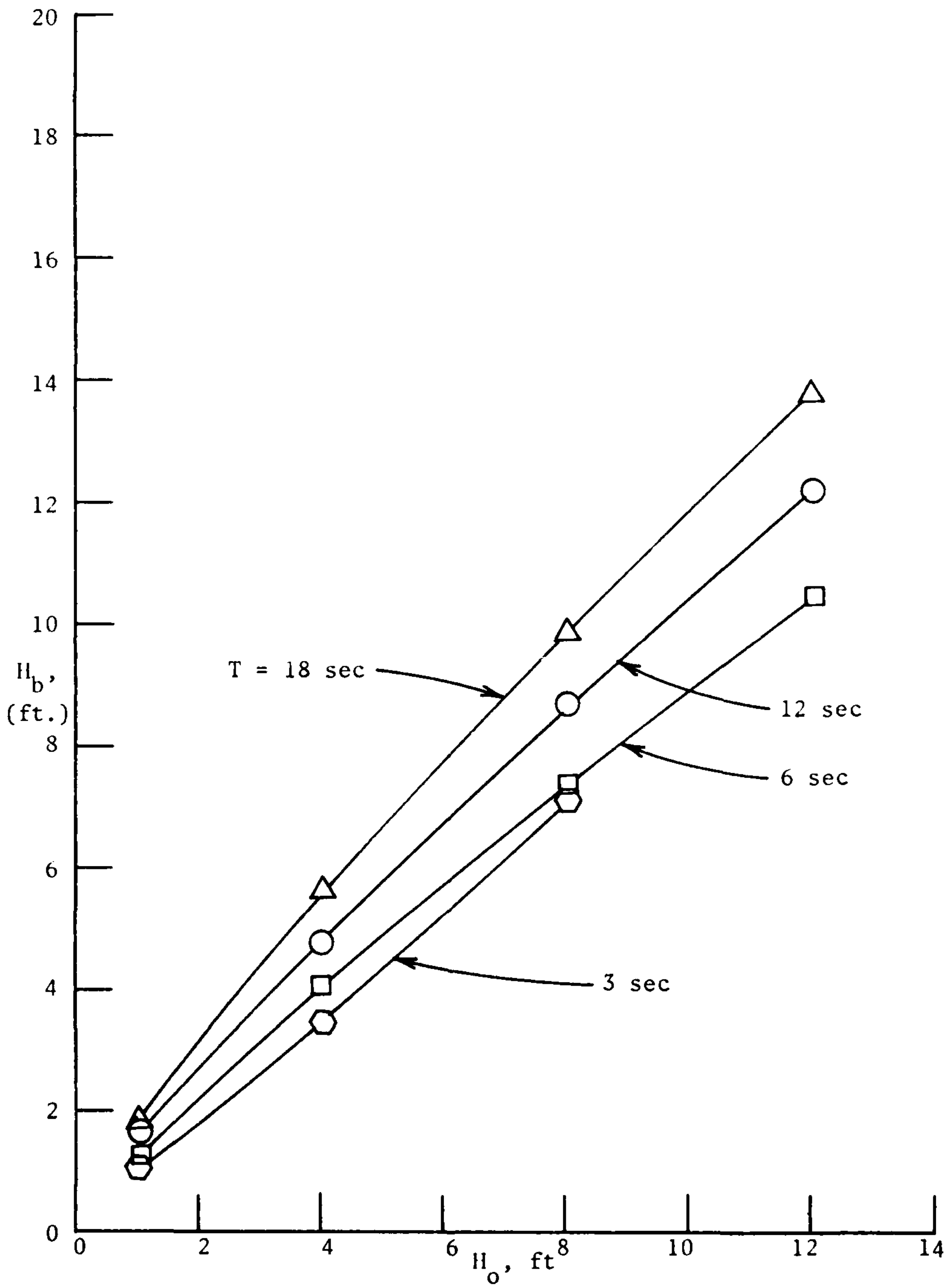

Figure C5. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Newport Beach region, Calif $\theta_{100} = 247°$

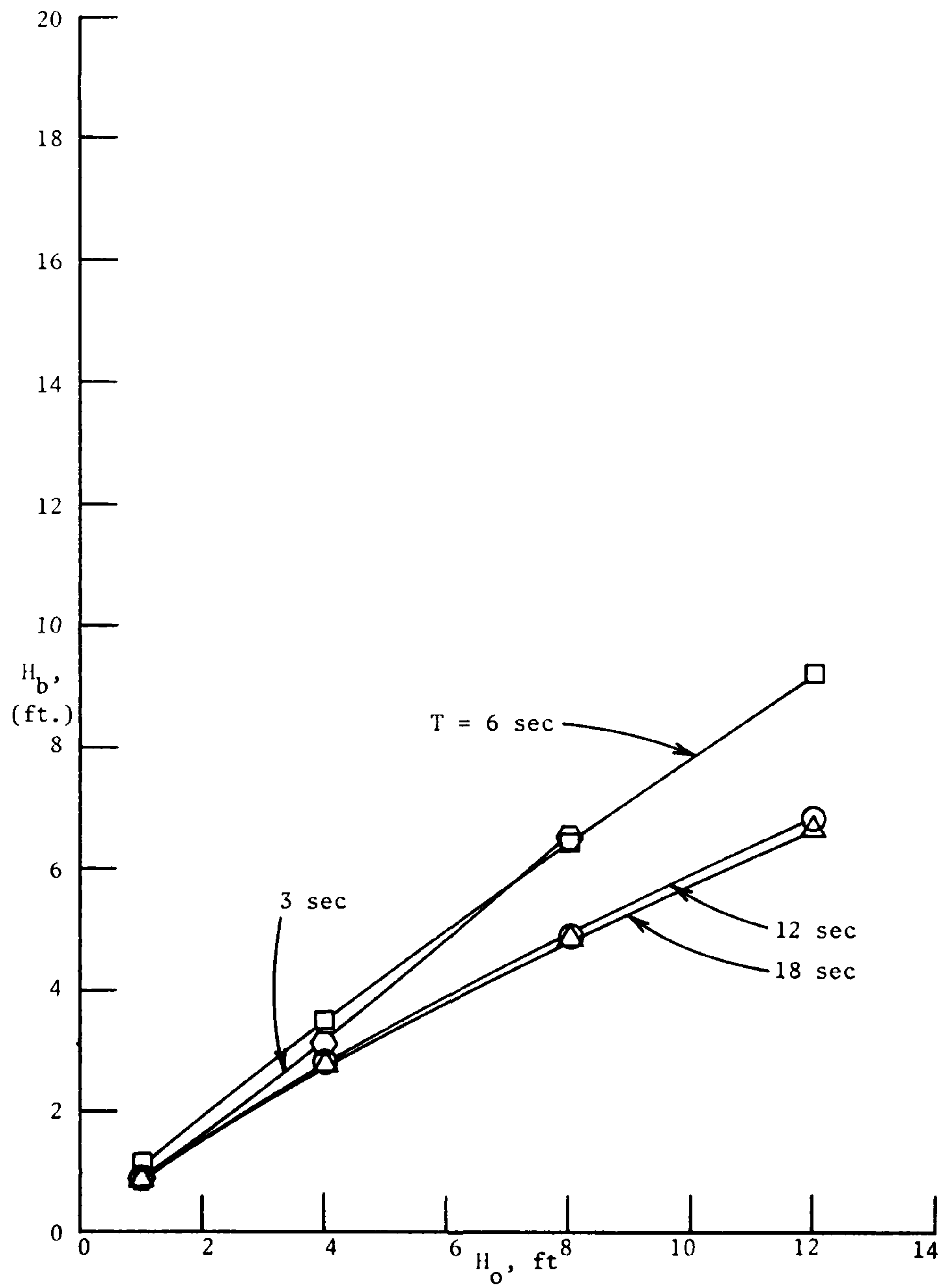

Figure C6. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Newport Beach region, Calif. $\theta_{100} = 270°$

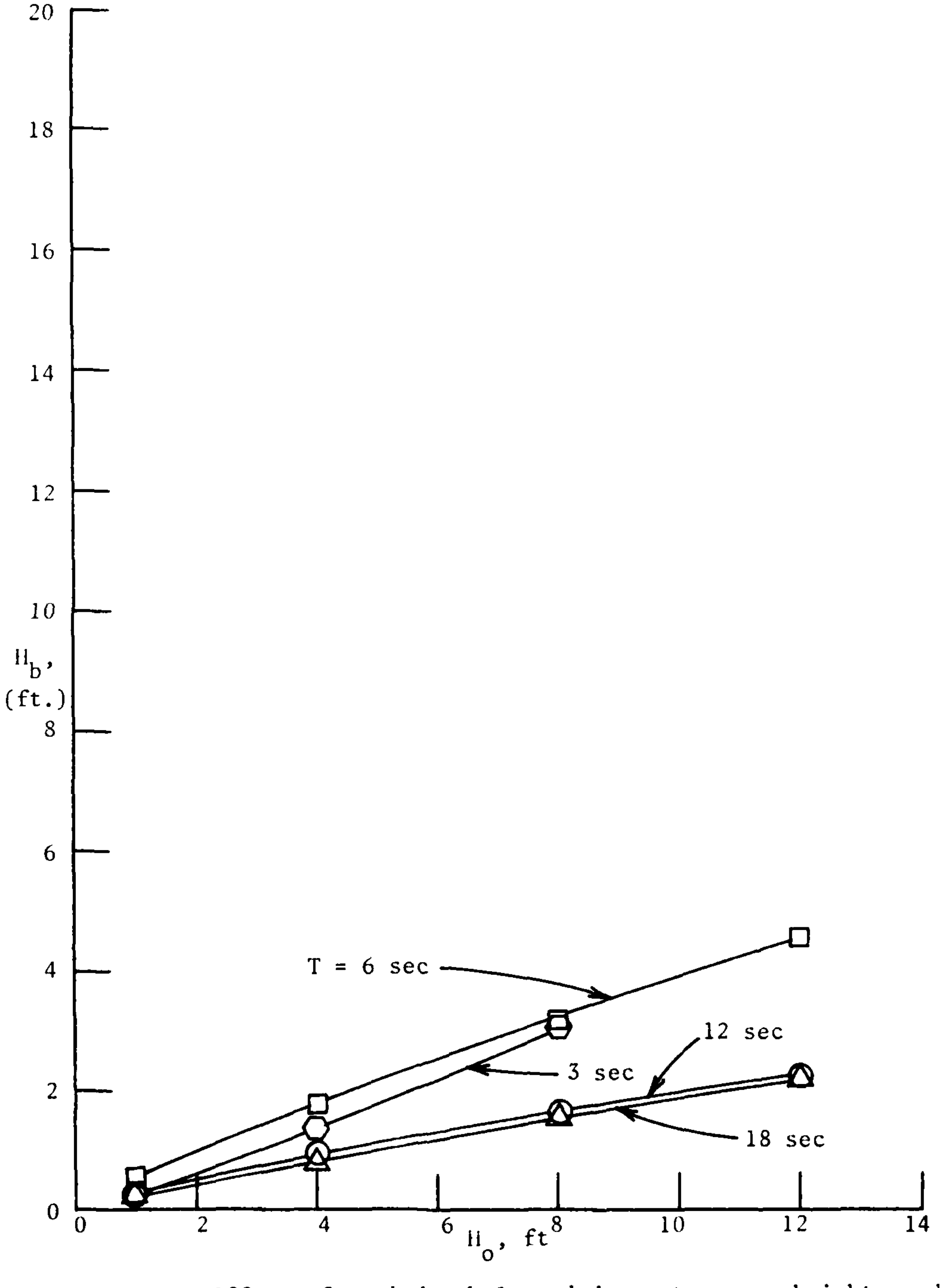

Figure C7. Effect of period, sheltered deepwater wave height, and angle of approach on breaker height, Newport Beach region, Calif, $\theta_{100} = 292°$

APPENDIX D: EFFECT OF PERIOD, SHELTERED DEEPWATER WAVE HEIGHT, AND ANGLE OF APPROACH ON BREAKER ANGLE

SURFSIDE-SUNSET BEACH REGION, CALIFORNIA

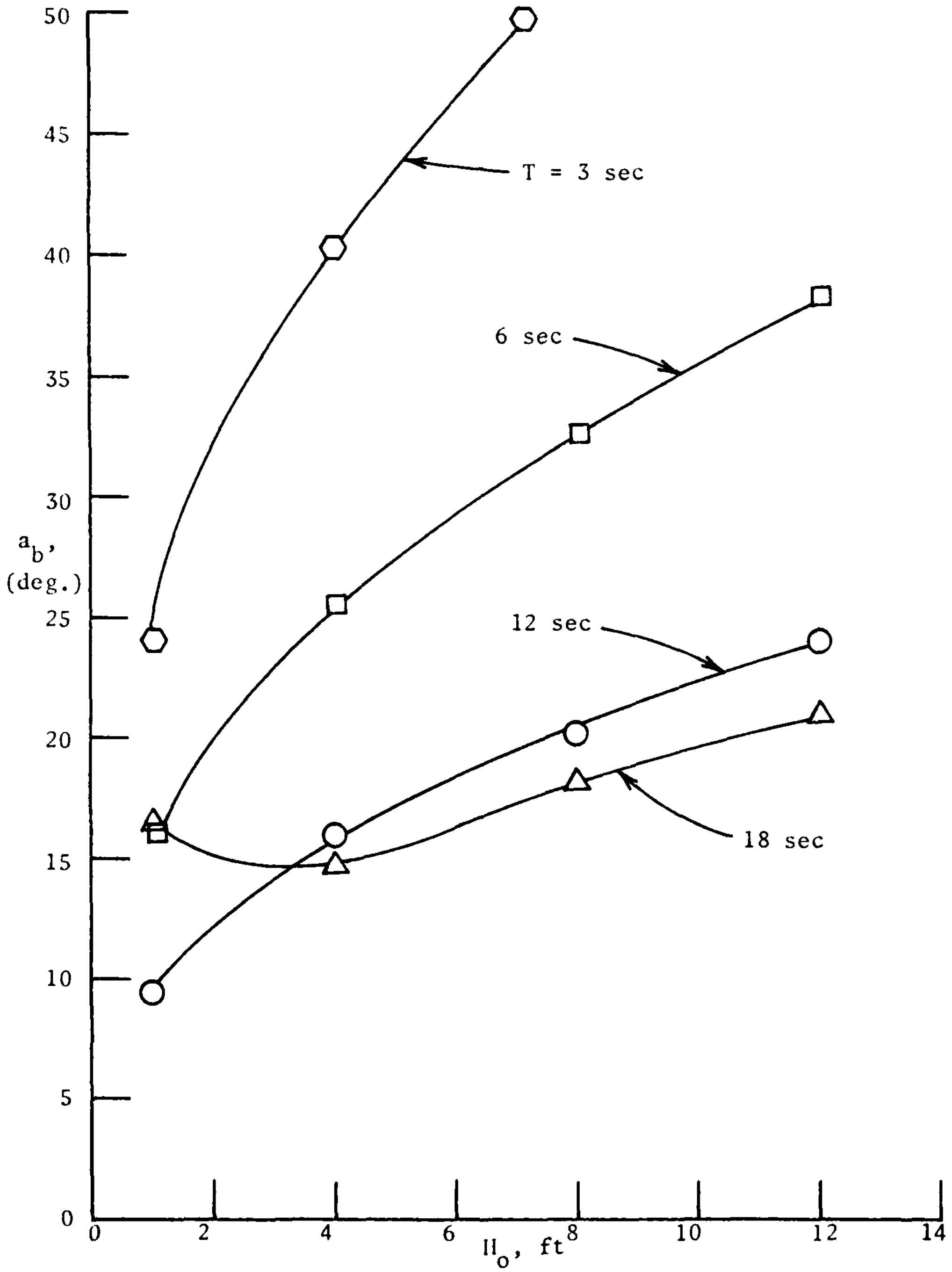

Figure D1. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Surfside-Sunset Beach region, Calif.
$\theta_{100} = 157°$

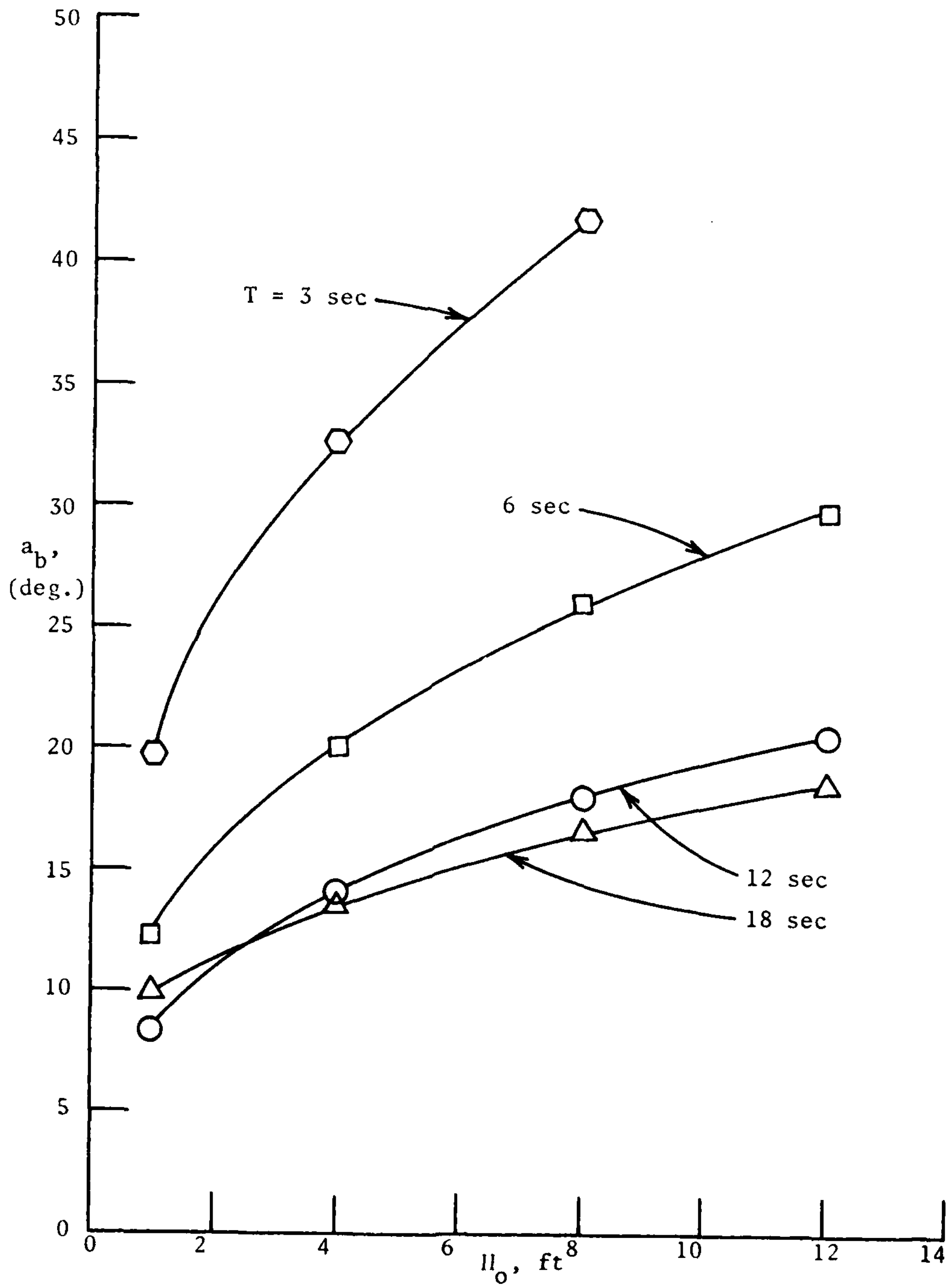

Figure D2. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Surfside-Sunset Beach region, Calif.
$\theta_{100} = 180°$

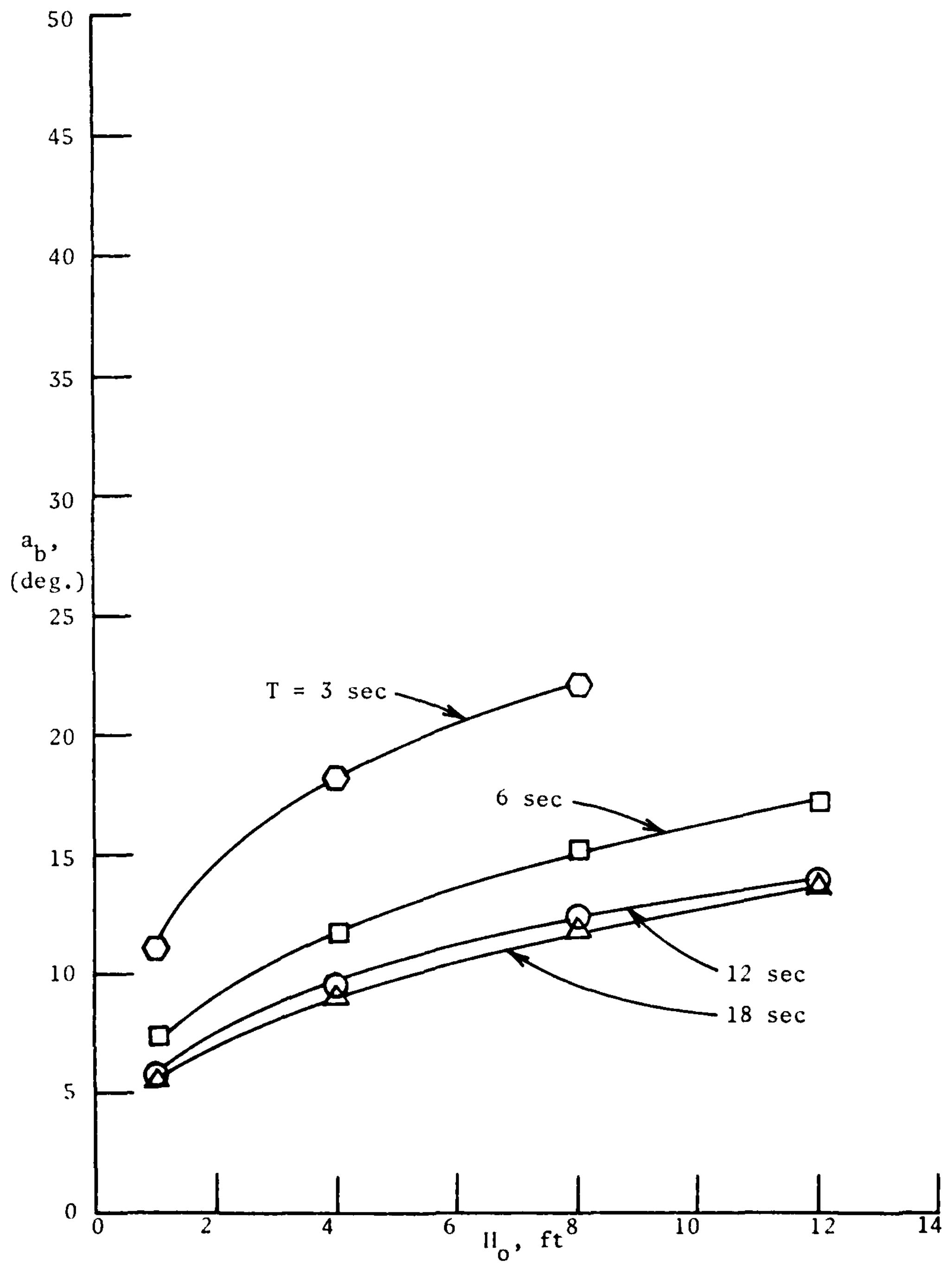

Figure D3. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Surfside-Sunset Beach region, Calif. $\theta_{100} = 202°$

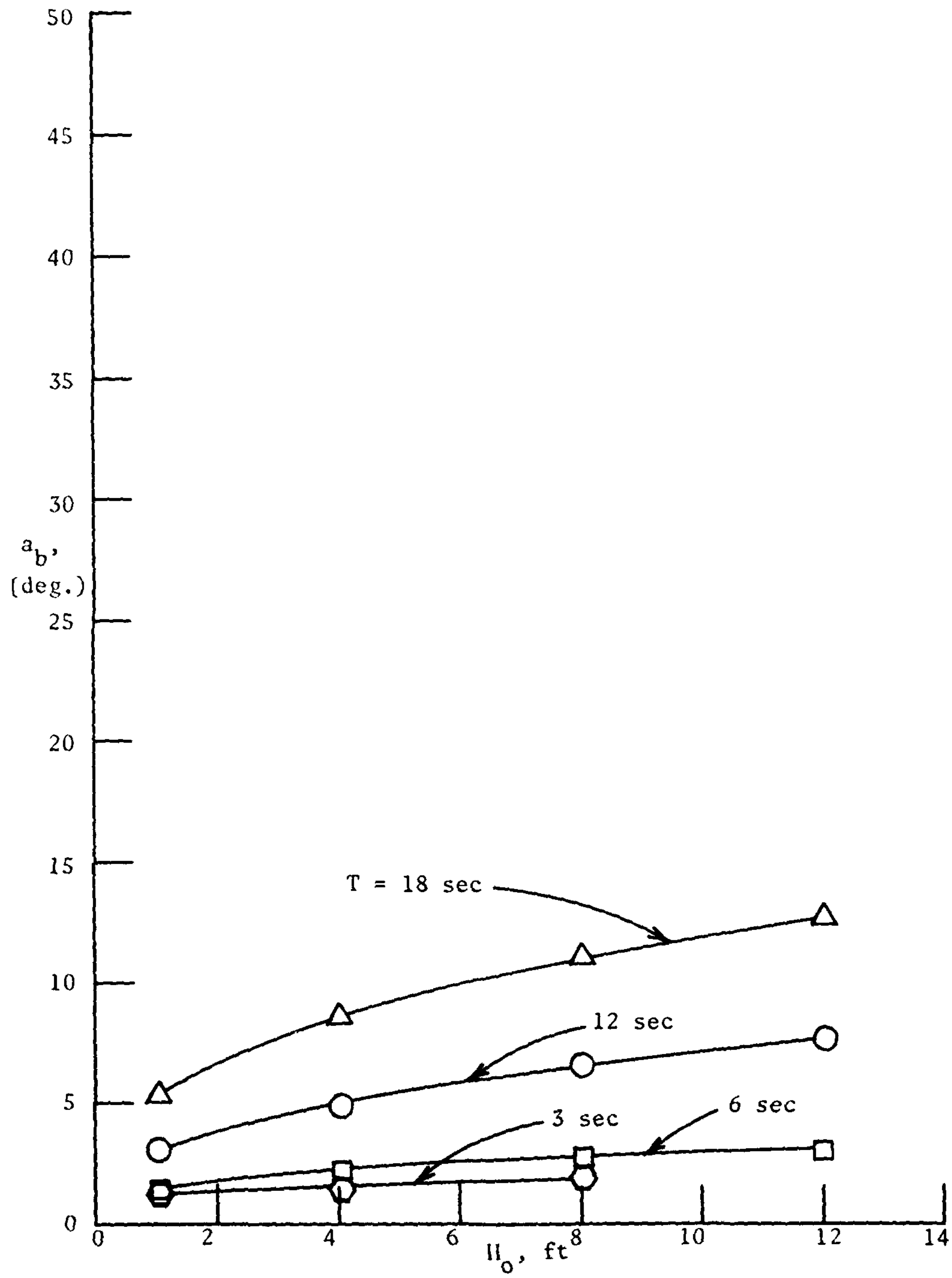

Figure D4. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Surfside-Sunset Beach region, Calif.
$\theta_{100} = 225°$

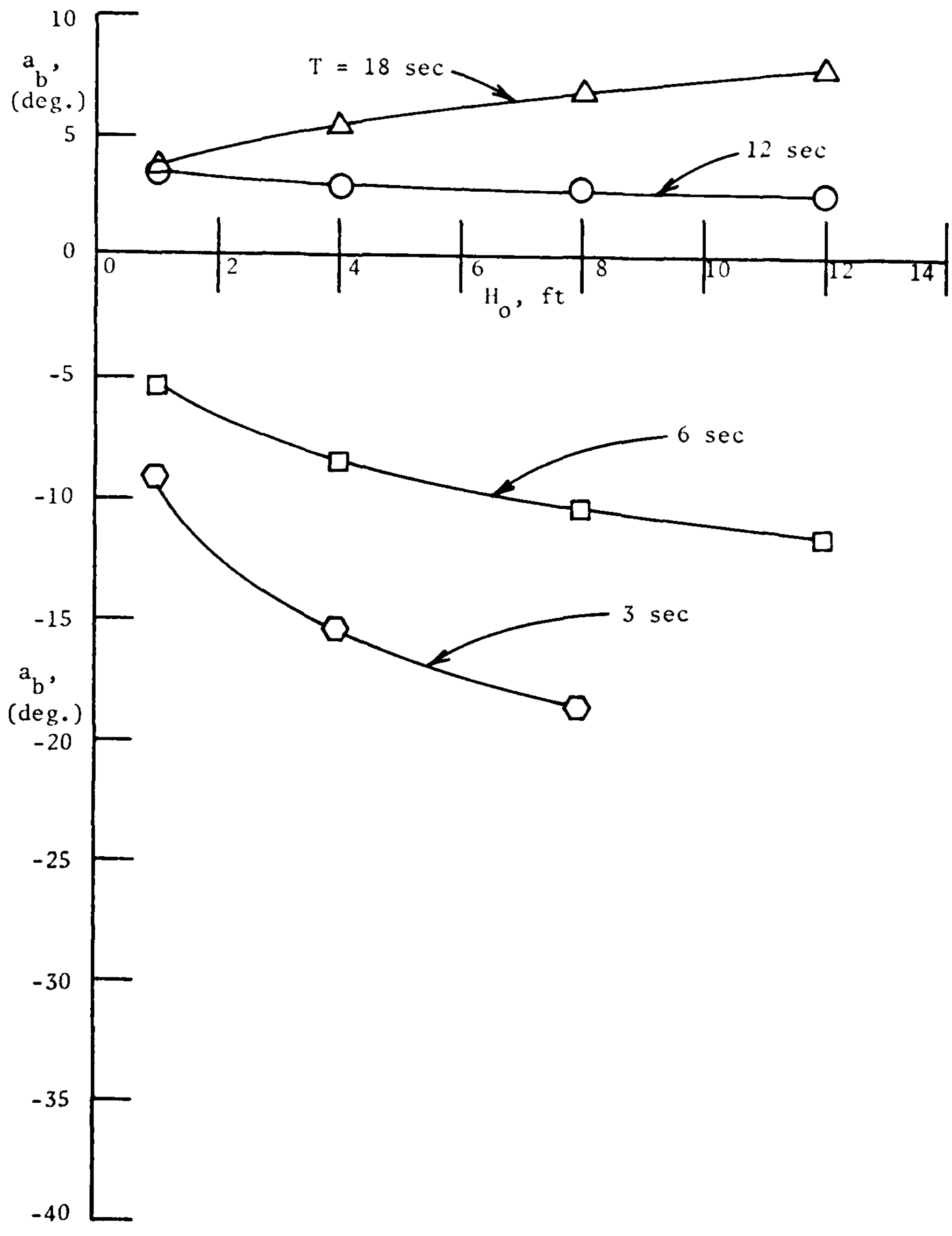

Figure D5. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Surfside-Sunset Beach region, Calif.
$\theta_{100} = 247°$

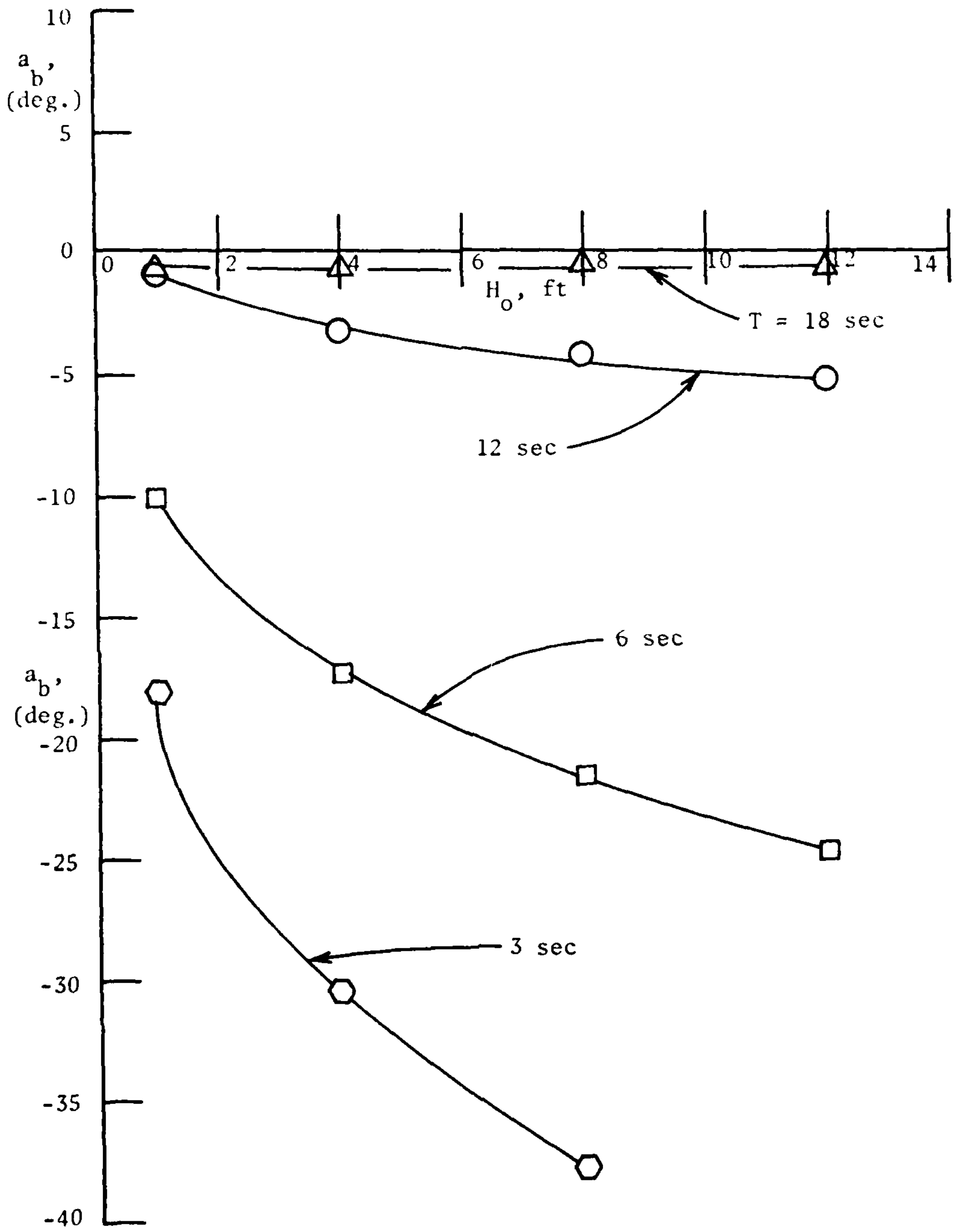

Figure D6. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Surfside-Sunset Beach region, Calif.
$\theta_{100} = 270°$

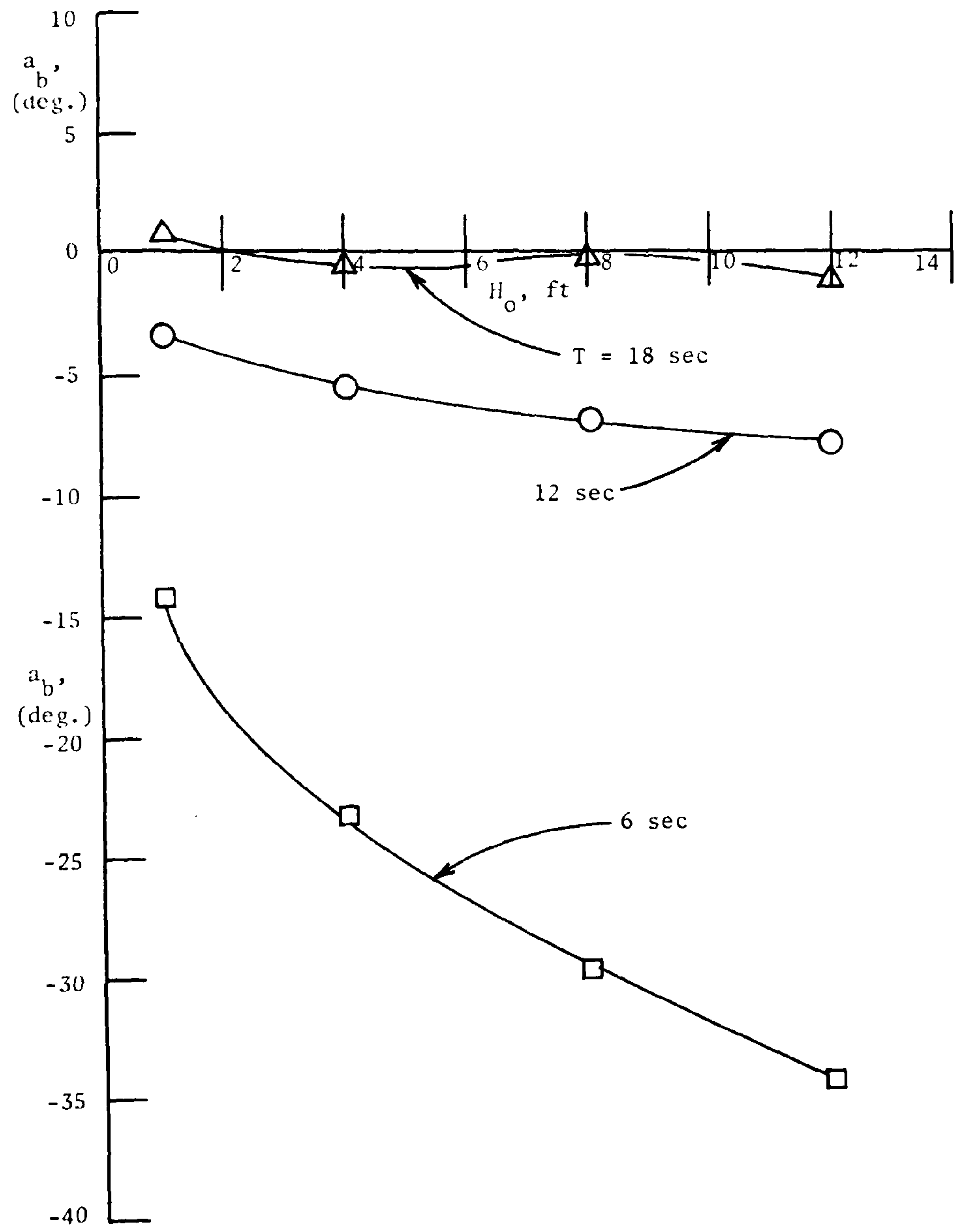

Figure D7. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Surfside-Sunset Beach region, Calif.
$\theta_{100} = 292°$

APPENDIX E: EFFECT OF PERIOD, SHELTERED DEEPWATER WAVE HEIGHT, AND ANGLE OF APPROACH ON BREAKER ANGLE

SANTA ANA RIVER MOUTH REGION, CALIFORNIA

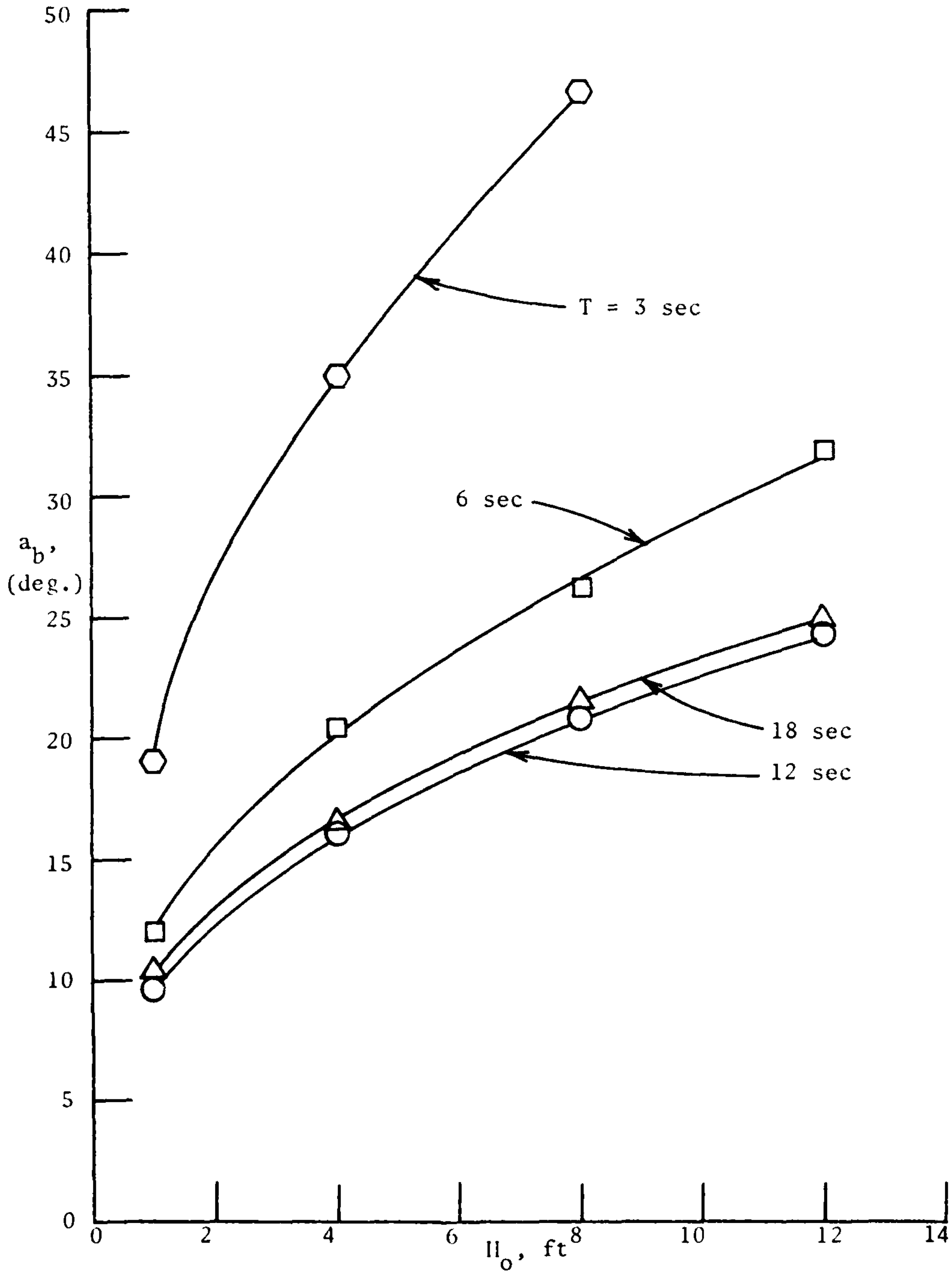

Figure E1. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Santa Ana River mouth region, Calif. $\theta_{100} = 157°$

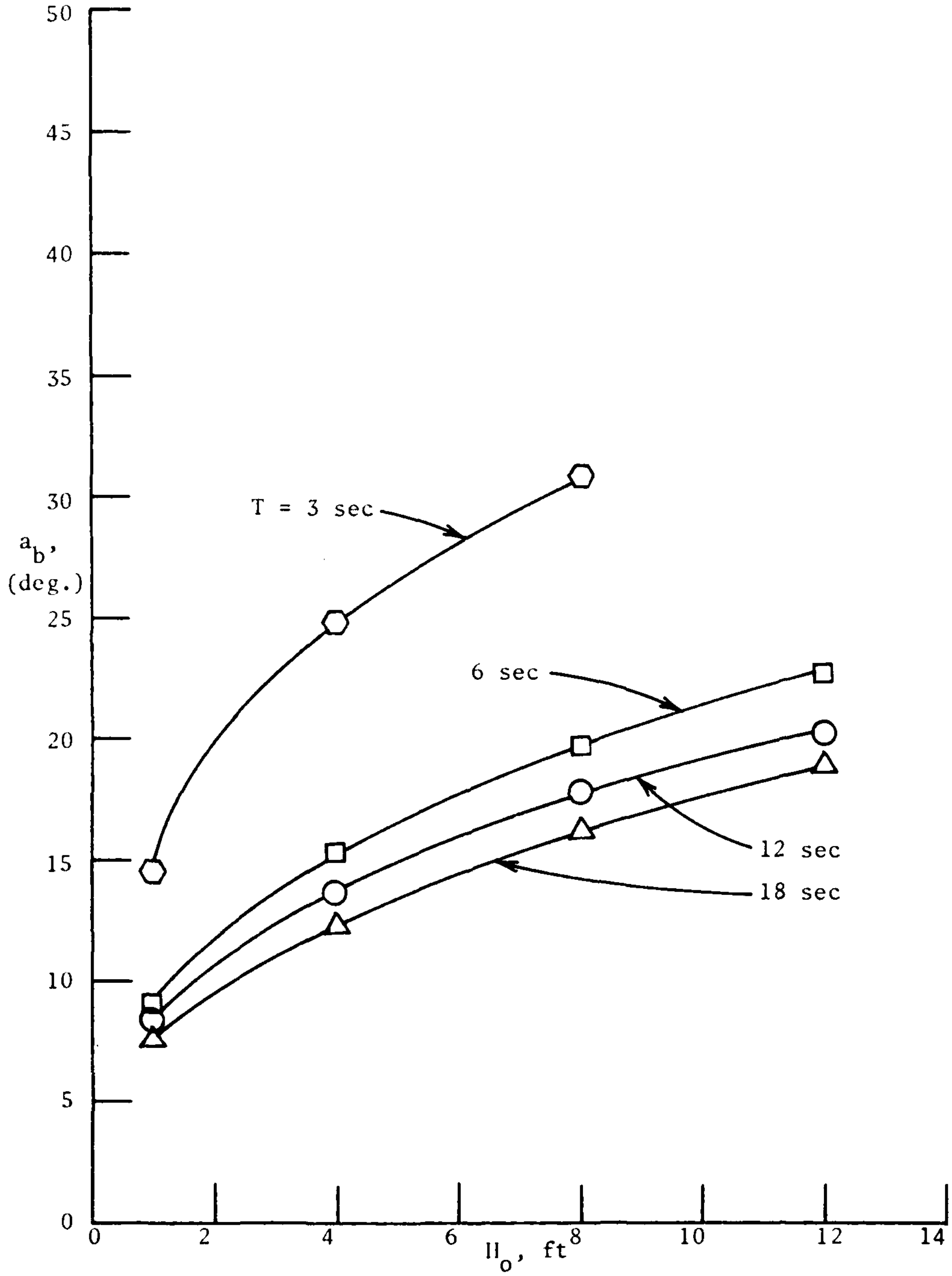

Figure E2. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Santa Ana River mouth region, Calif. $\theta_{100} = 180°$

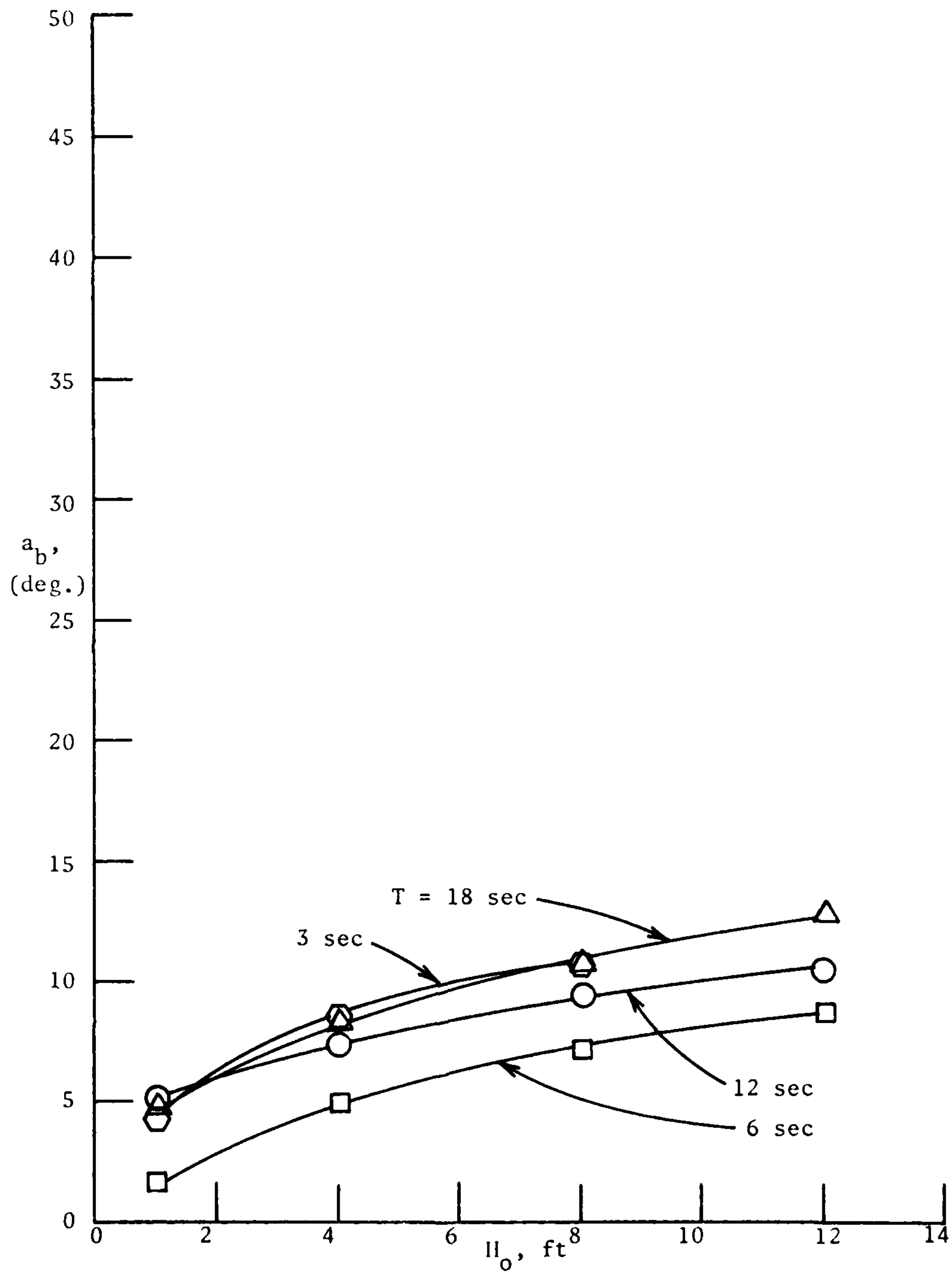

Figure E3. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Santa Ana River mouth region, Calif. $\theta_{100} = 202°$

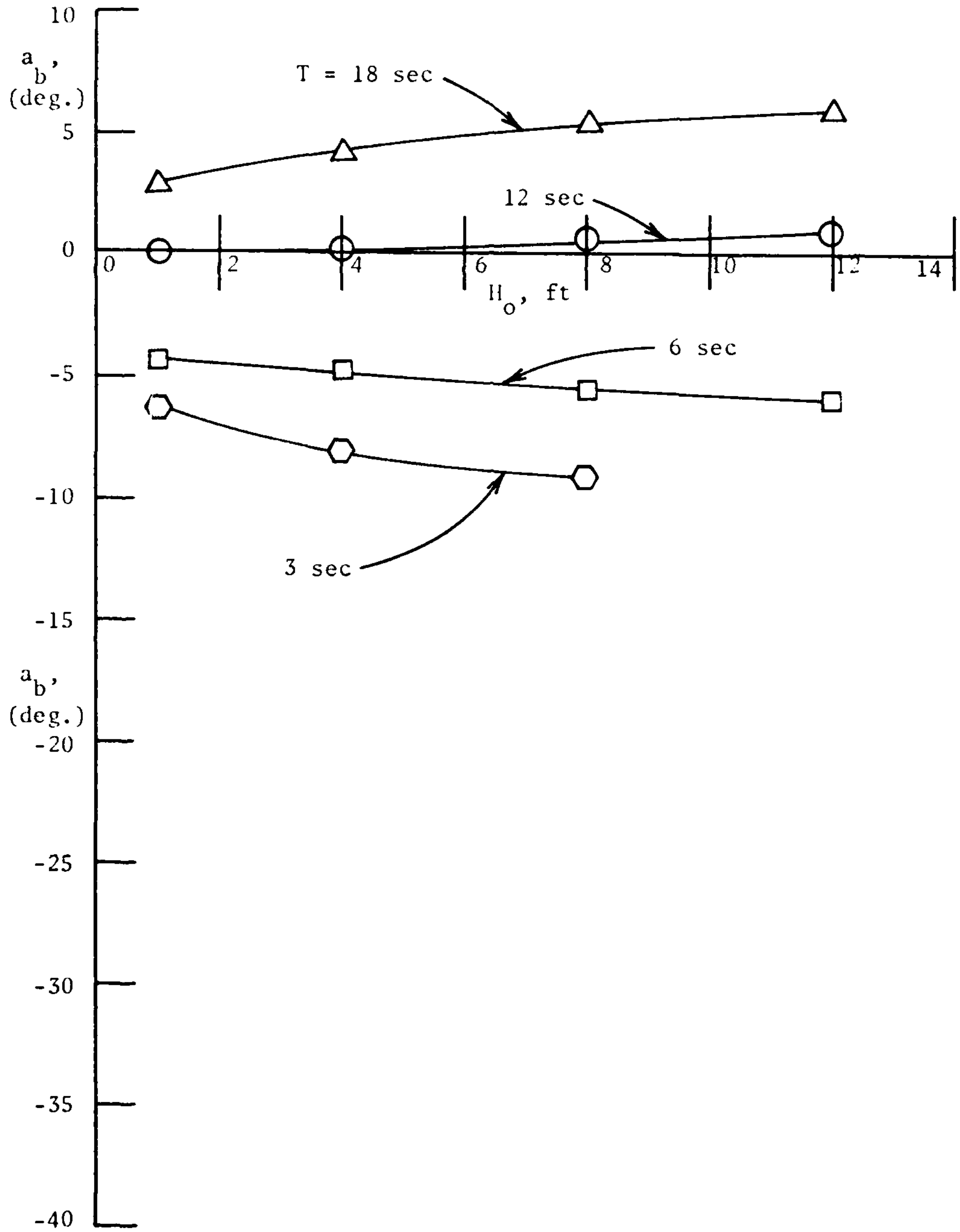

Figure E4. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Santa Ana River mouth region, Calif.
$\theta_{100} = 225°$

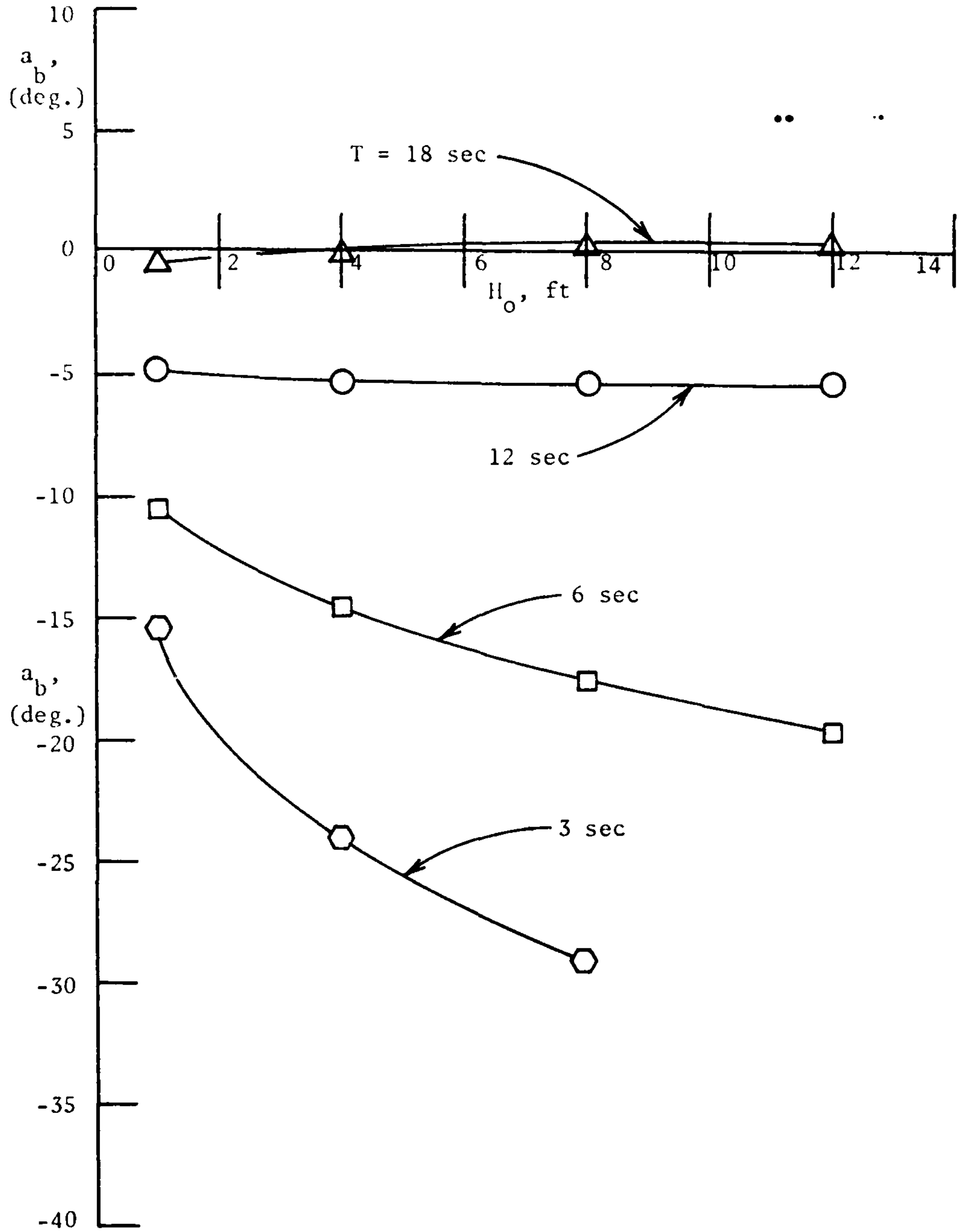

Figure E5. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Santa Ana River mouth region, Calif. $\theta_{100} = 247°$

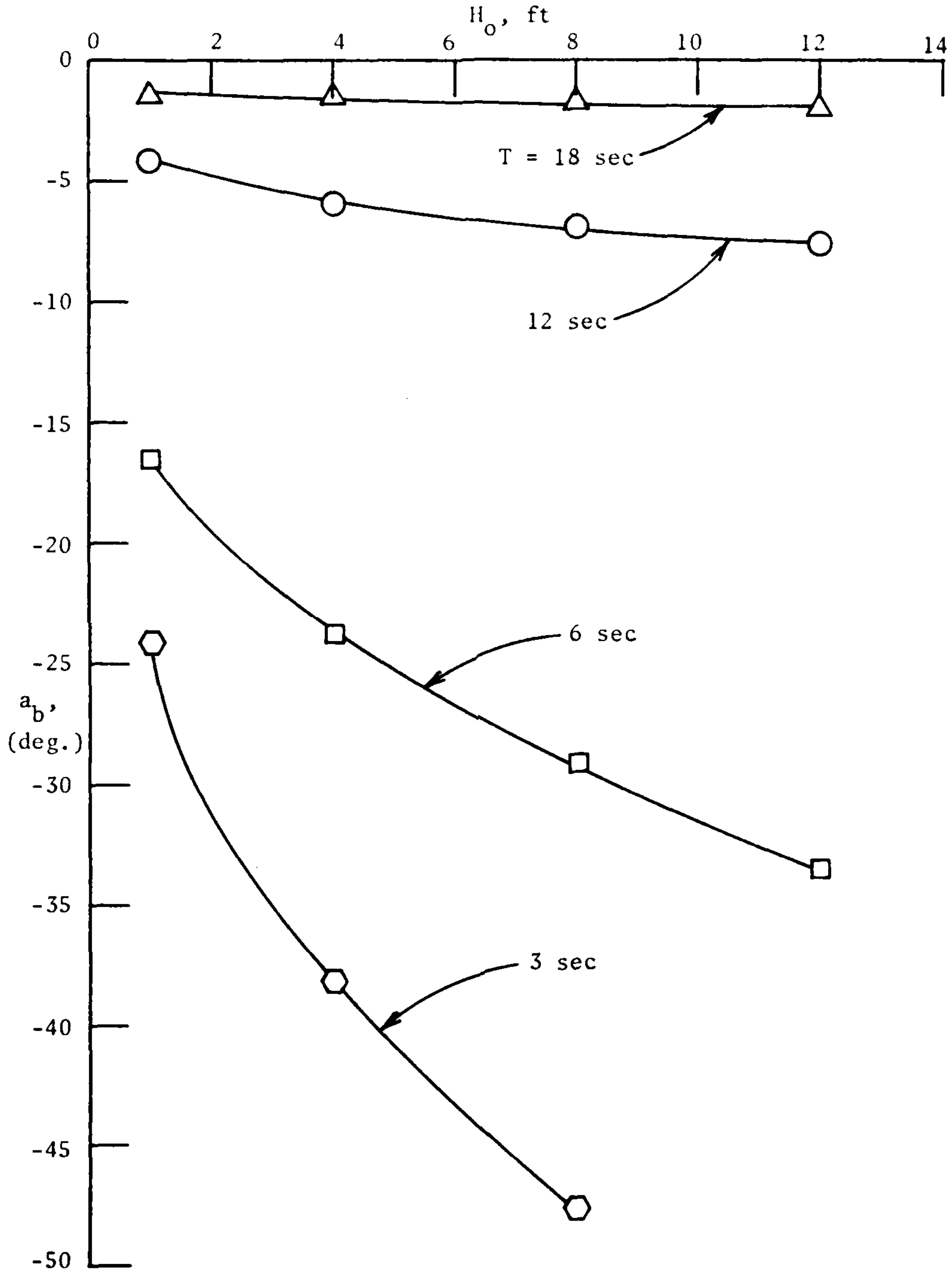

Figure E6. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Santa Ana River mouth region, Calif.
$\theta_{100} = 270°$

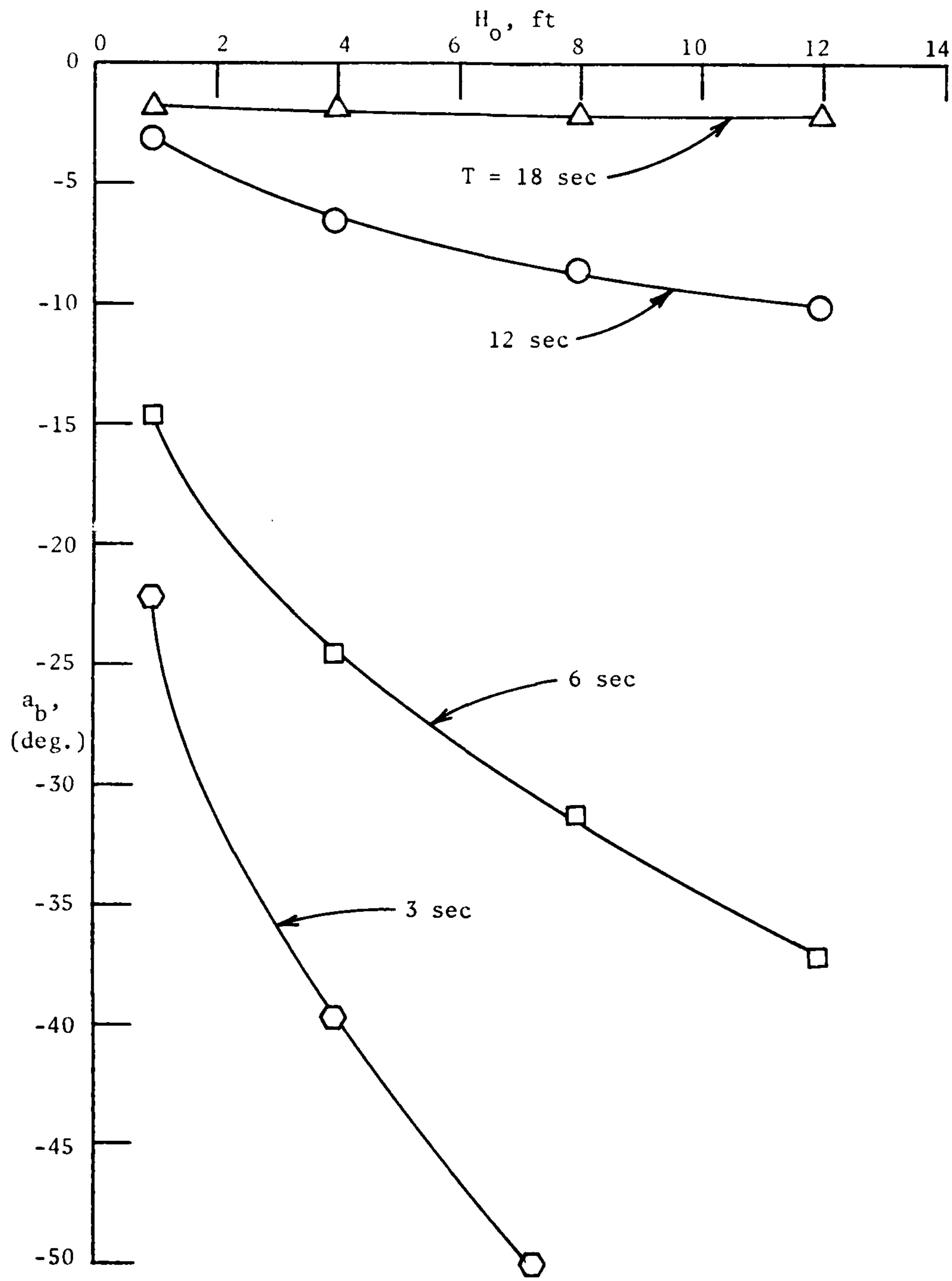

Figure E7. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Santa Ana River mouth region, Calif. $\theta_{100} = 292°$

APPENDIX F: EFFECT OF PERIOD, SHELTERED DEEPWATER WAVE HEIGHT, AND ANGLE OF APPROACH ON BREAKER ANGLE

NEWPORT BEACH REGION, CALIFORNIA

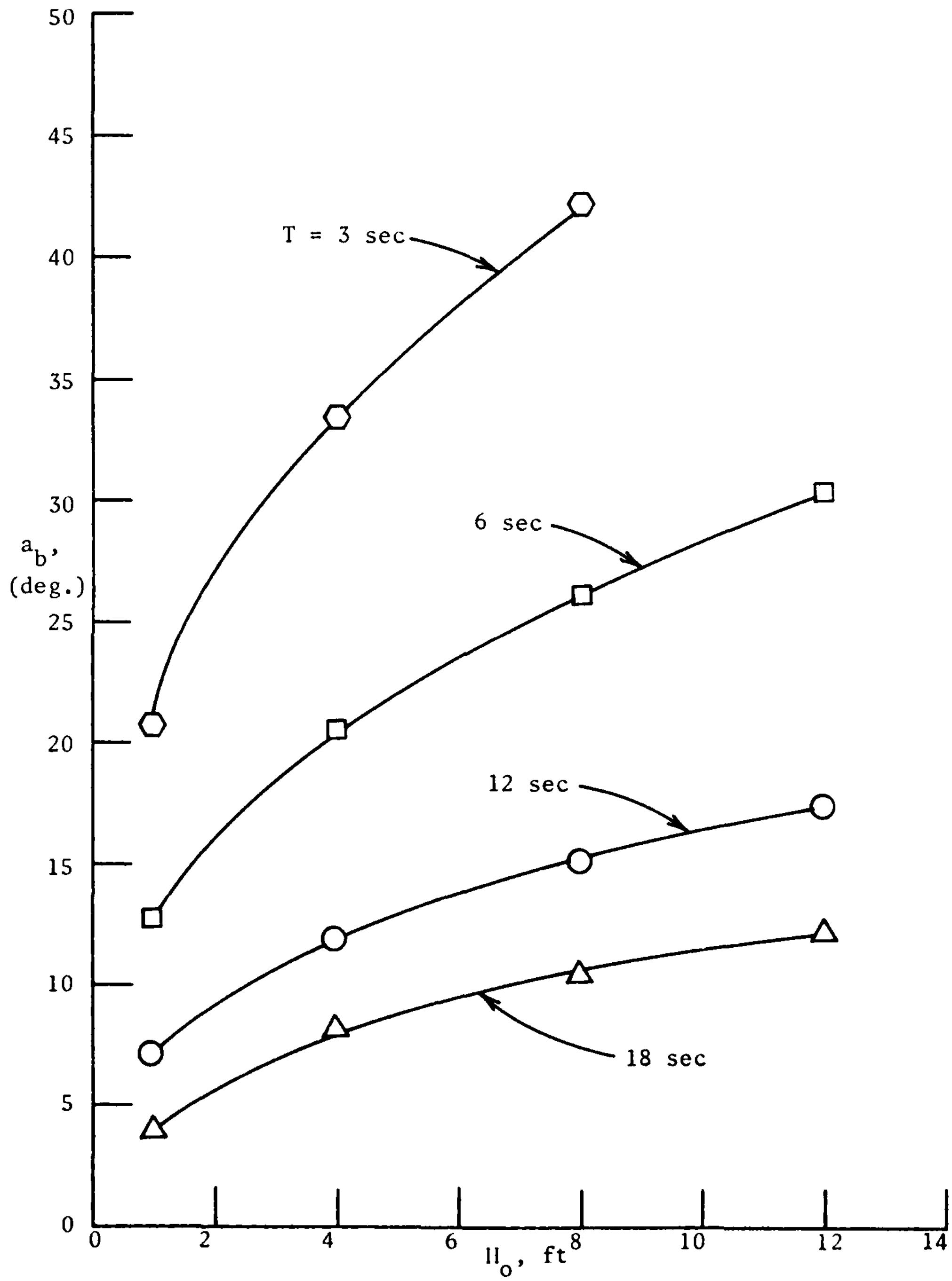

Figure F1. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Newport Beach region, Calif. $\theta_{100} = 157°$

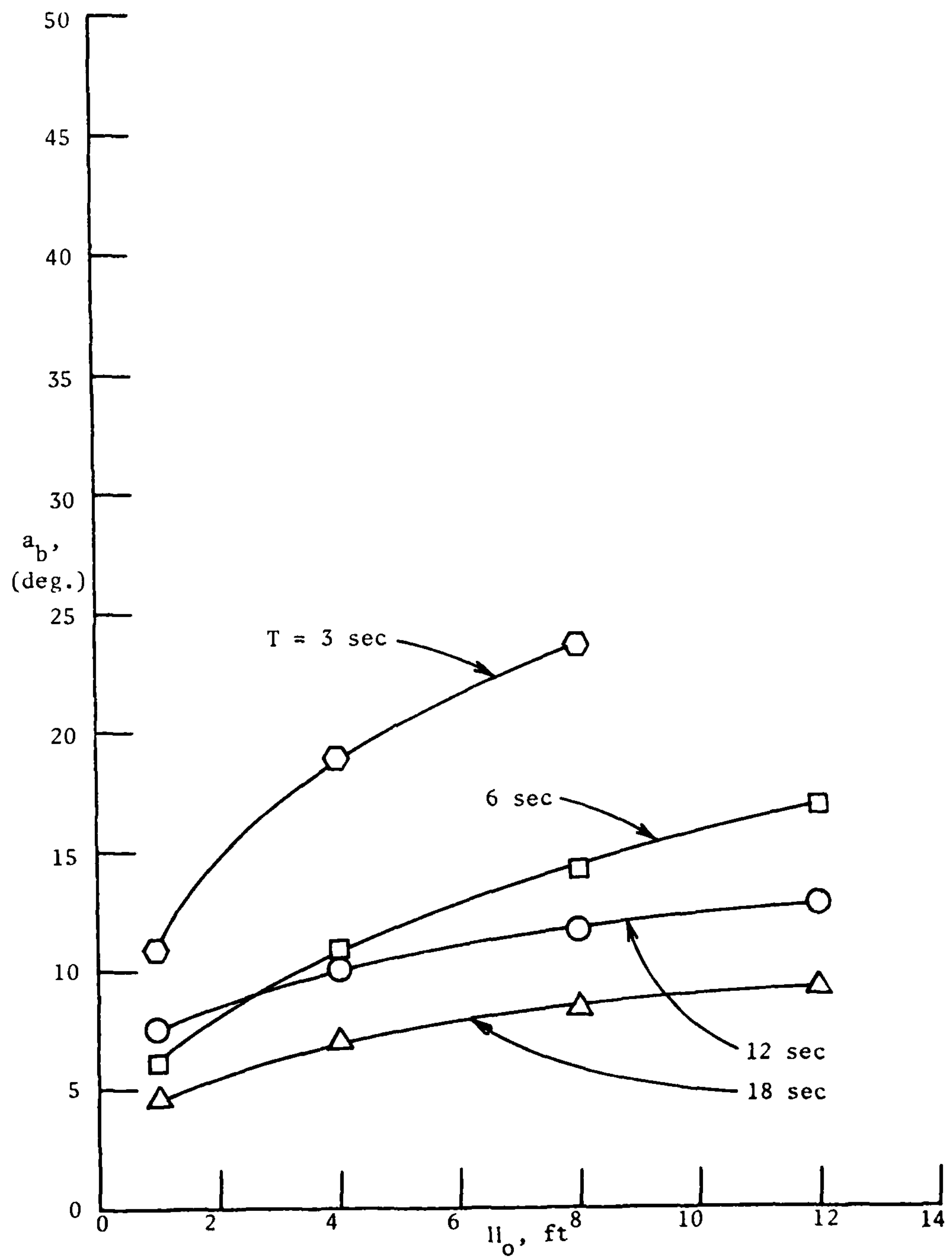

Figure F2. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Newport Beach region, Calif. $\theta_{100} = 180°$

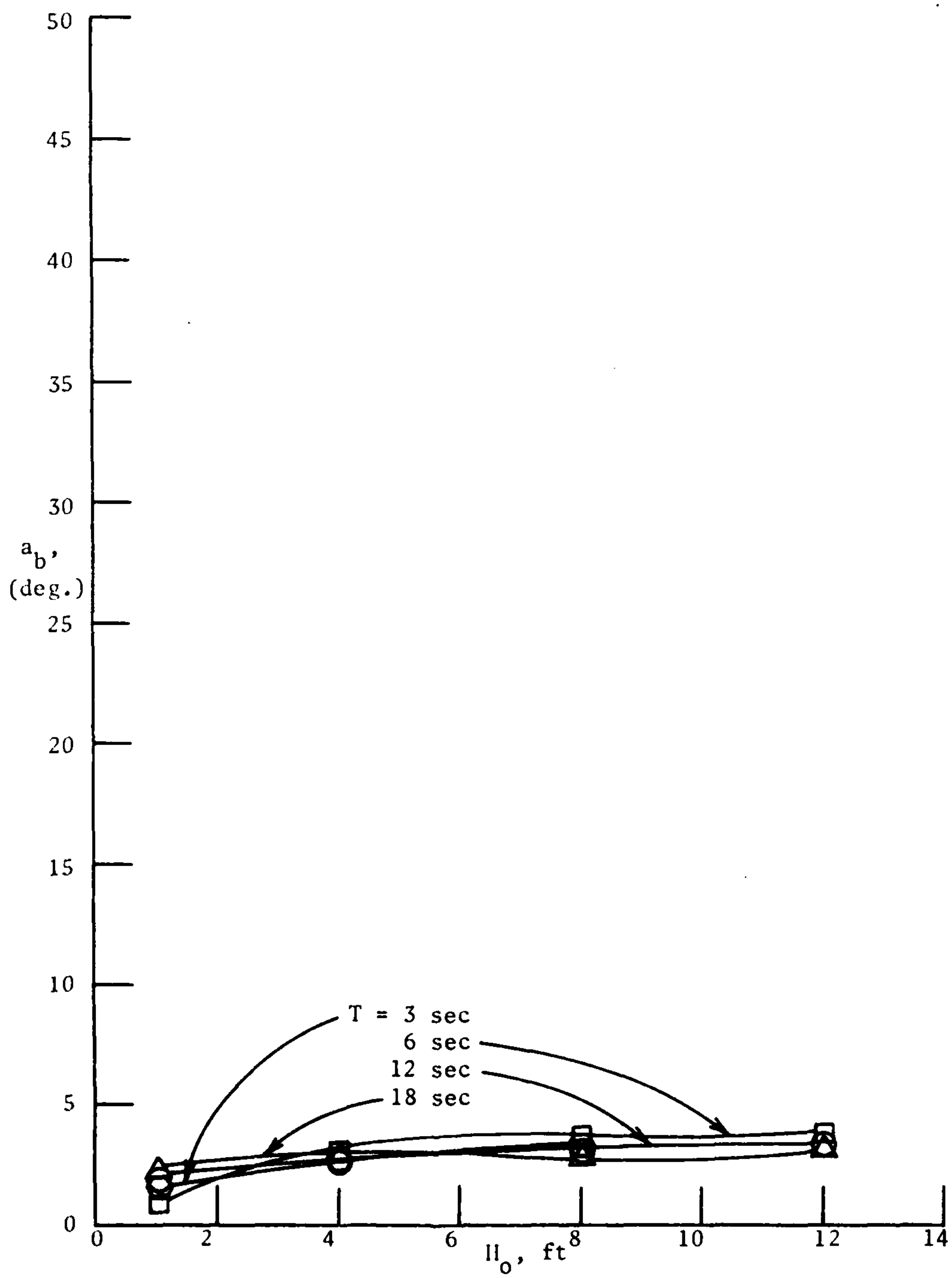

Figure F3. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Newport Beach region, Calif. $\theta_{100} = 202°$

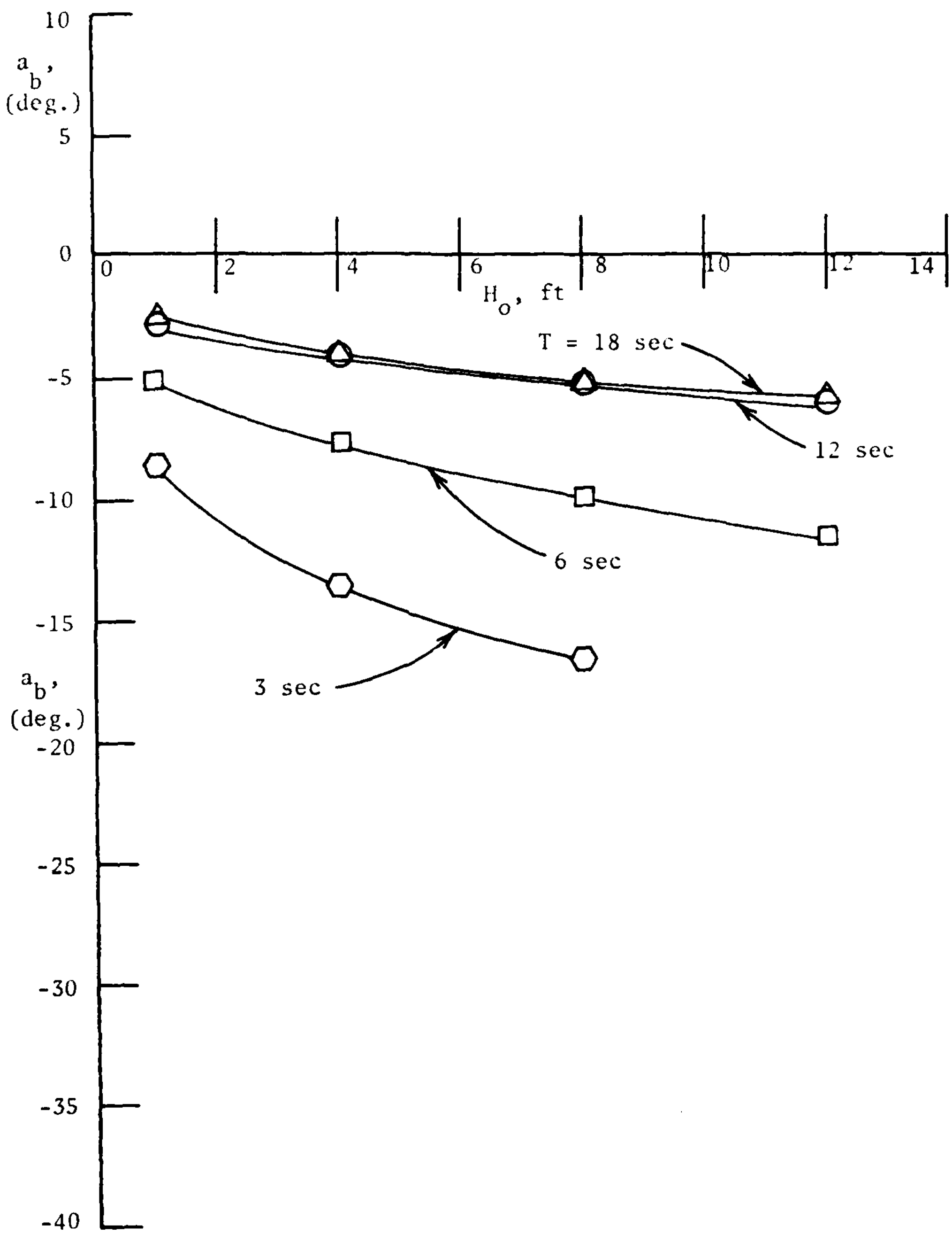

Figure F4. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Newport Beach region, Calif. $\theta_{100} = 225°$

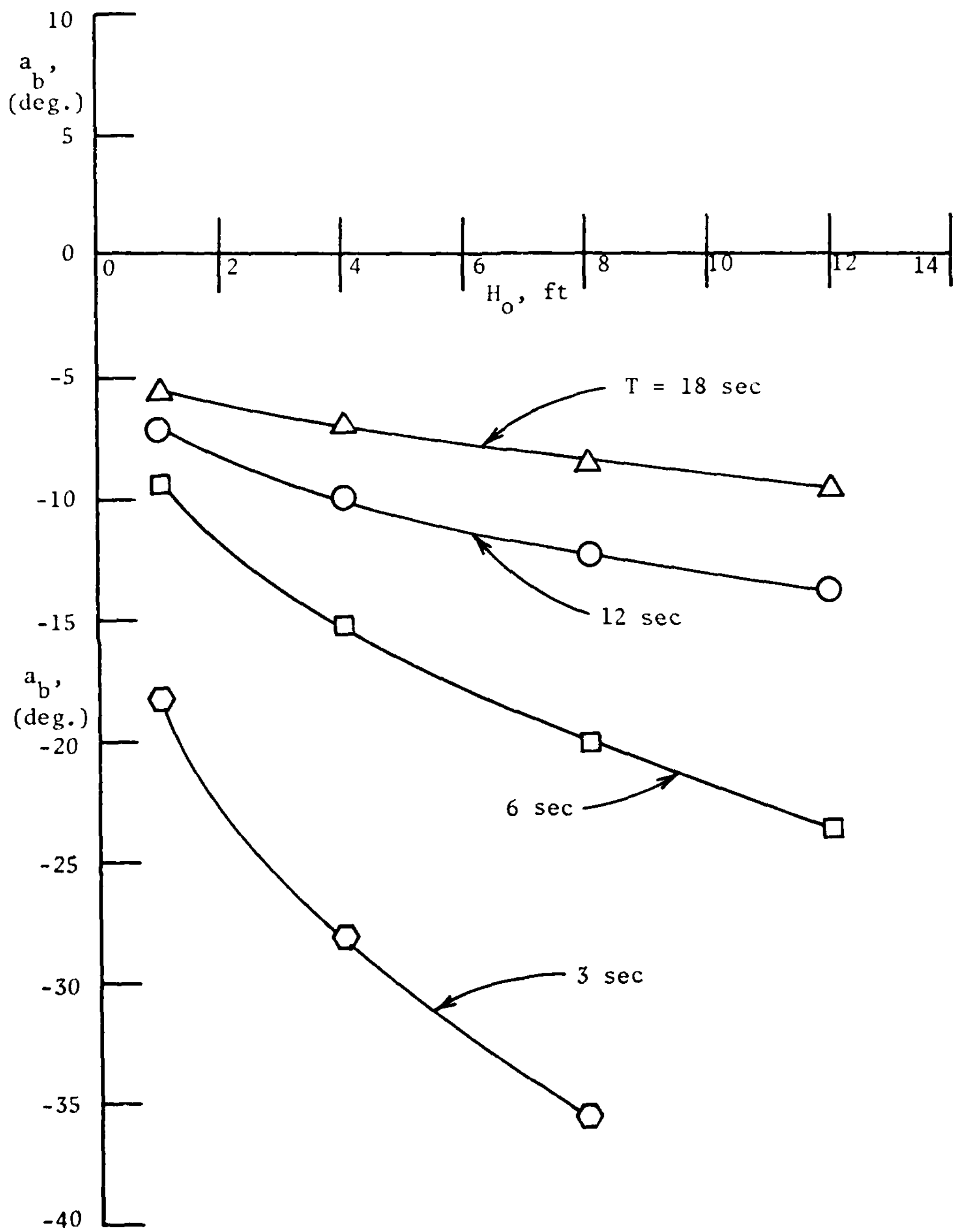

Figure F5. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Newport Beach region, Calif. $\theta_{100} = 247°$

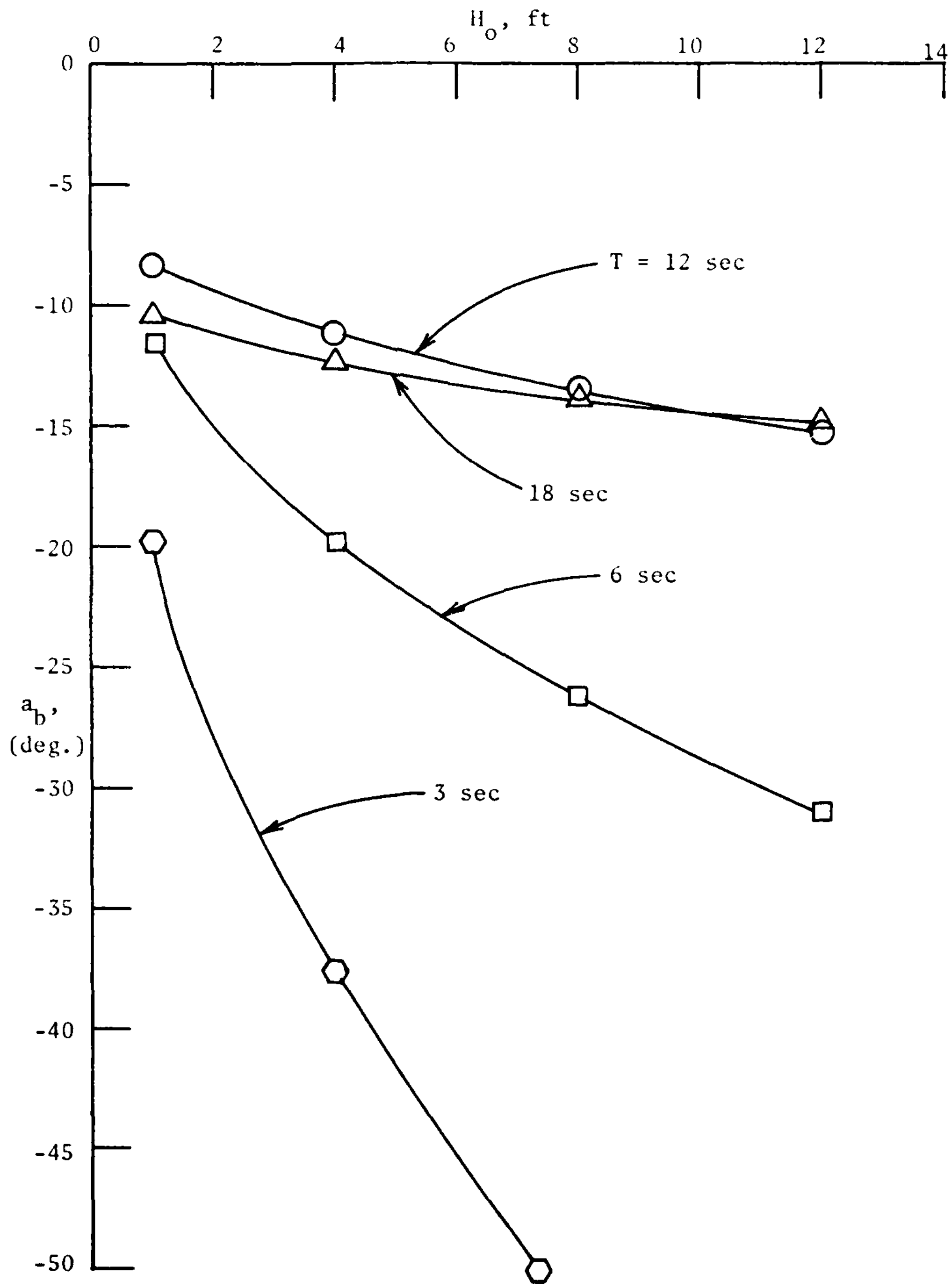

Figure F6. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Newport Beach region, Calif. $\theta_{100} = 270°$

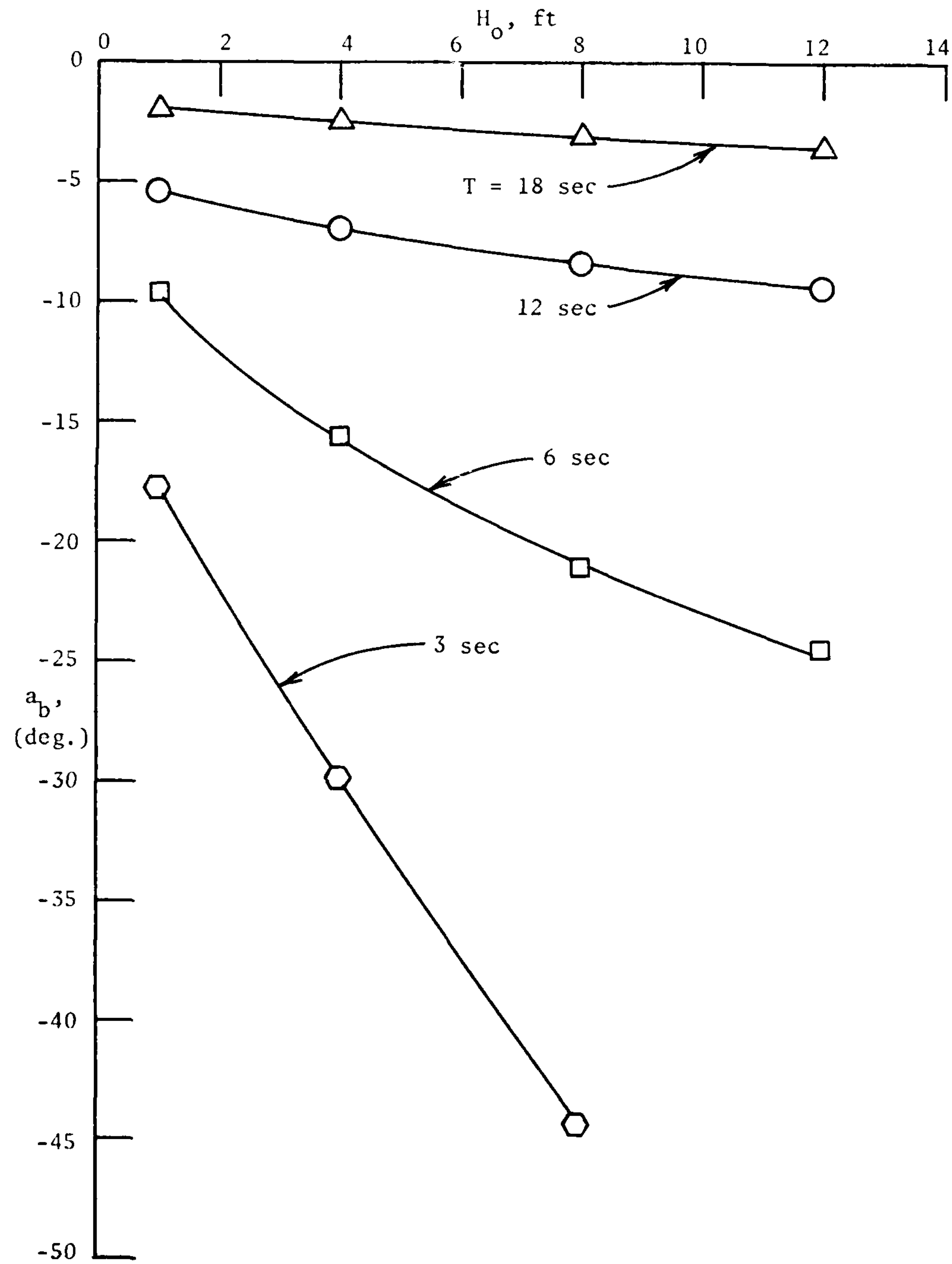

Figure F7. Effect of period, sheltered deepwater wave height, and angle of approach on breaker angle, Newport Beach region, Calif. $\theta_{100} = 292°$

APPENDIX G: OPEN-OCEAN DEEPWATER WAVE STATISTICS
SOUTHERN HEMISPHERE AND NORTHERN HEMISPHERE SWELL
(Sea statistics were available at a sheltered station)

Table G1

Frequency of Annual Occurrence

Open-Ocean Deep Water

Southern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = 155° - 164°

Significant Wave Height, ft	Wave Period, sec				
	12-13.9	14-15.9	16-17.9	18-19.9	20+
0.0-0.9	2.1	1.2	1.0	0.1	
1.0-1.9	3.5	3.0	1.7	0.2	
2.0-2.9	1.2	1.1	0.5	0.1	
3.0-3.9	0.2	0.2	0.1		
4.0-4.9					
5.0-5.9					
6.0-6.9					

These data are Station A data from "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Marine Advisers, January 1961.

Table G2

Frequency of Annual Occurrence

Open-Ocean Deep Water

Southern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = $165^{\circ} - 174^{\circ}$

Significant Wave Height, ft	Wave Period, sec				
	12-13.9	14-15.9	16-17.9	18-19.9	20+
0.0-0.9	1.1	1.1	0.5		
1.0-1.9	2.5	1.8	0.8	0.2	0.2
2.0-2.9	0.3	0.5			
3.0-3.9	0.1				
4.0-4.9					
5.0-5.9					
6.0-6.9					

These data are Station A data from "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Marine Advisers, January 1961.

Table G3

Frequency of Annual Occurrence

Open-Ocean Deep Water

Southern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = 175^{o} - 184^{o}

Significant Wave Height, ft	Wave Period, sec				
	12-13.9	14-15.9	16-17.9	18-19.9	20+
0.0-0.9	1.8	1.0	0.4	0.1	0.1
1.0-1.9	2.2	1.4	0.5		
2.0-2.9	0.4	0.1	0.1		
3.0-3.9					
4.0-4.9					
5.0-5.9					
6.0-6.9					

These data are Station A data from "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Marine Advisers, January 1961.

Table G4

Frequency of Annual Occurrence

Open-Ocean Deep Water

Southern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = 185° - 194°

Significant Wave Height, ft	Wave Period, sec				
	12-13.9	14-15.9	16-17.9	18-19.9	20+
0.0-0.9	0.4	0.3	0.2		
1.0-1.9	0.5	0.3	0.1		
2.0-2.9		0.1			
3.0-3.9					
4.0-4.9					
5.0-5.9					
6.0-6.9					

These data are Station A data from "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Marine Advisers, January 1961.

Table G5

Frequency of Annual Occurrence

Open-Ocean Deep Water

Southern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = 195^{o} - 204^{o}

Significant Wave Height, ft	Wave Period, sec				
	12-13.9	14-15.9	16-17.9	18-19.9	20+
0.0-0.9	1.2	0.5		0.2	
1.0-1.9	1.2	0.9	0.2		
2.0-2.9	0.5	0.7	0.2	0.1	
3.0-3.9		0.2	0.2	0.1	
4.0-4.9					
5.0-5.9					
6.0-6.9					

These data are Station A data from "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Marine Advisers, January 1961.

Table G6

Frequency of Annual Occurrence

Open-Ocean Deep Water

Southern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = 205^{o} - 214^{o}

Significant Wave Height, ft	Wave Period, sec				
	12-13.9	14-15.9	16-17.9	18-19.9	20+
0.0-0.9	1.1	0.5			
1.0-1.9	3.1	2.4	0.3		
2.0-2.9	0.3	0.5	0.2		
3.0-3.9	0.1	0.2	0.2		
4.0-4.9					
5.0-5.9					
6.0-6.9					

These data are Station A data from "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Marine Advisers, January 1961.

Table G7

Frequency of Annual Occurrence

Open-Ocean Deep Water

Northern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = 150° - 159°

Significant Wave Height, ft	Wave Period, sec				
	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9
0.0-0.9					
1.0-1.9		0.1			
2.0-2.9			0.1		
3.0-3.9			0.2		
4.0-4.9					
5.0-5.9					
6.0-7.9					
8.0-9.9					

These data are Station A data from "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Marine Advisers, January 1961.

Table G8

Frequency of Annual Occurrence

Open-Ocean Deep Water

Northern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = 160^{o} - 169^{o}

Significant Wave Height, ft	Wave Period, sec				
	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9
0.0-0.9					
1.0-1.9					
2.0-2.9					
3.0-3.9					
4.0-4.9					0.1
5.0-5.9					
6.0-7.9					
8.0-9.9					

These data are Station A data from "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Marine Advisers, January 1961.

Table G9

Frequency of Annual Occurrence

Open-Ocean Deep Water

Northern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = 170° - 179°

Significant Wave Height, ft	Wave Period, sec				
	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9
0.0-0.9					
1.0-1.9	0.1				
2.0-2.9					
3.0-3.9				0.1	
4.0-4.9				0.1	
5.0-5.9					
6.0-7.9					
8.0-9.9					

These data are Station A data from "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Marine Advisers, January 1961.

Table G10

Frequency of Annual Occurrence

Open-Ocean Deep Water

Northern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = 180° - 189°

Significant Wave Height, ft	Wave Period, sec				
	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9
0.0-0.9					
1.0-1.9	0.1	0.1			
2.0-2.9		0.1	0.1		
3.0-3.9					
4.0-4.9					
5.0-5.9					
6.0-7.9					
8.0-9.9					

These data are Station A data from "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Marine Advisers, January 1961.

Table G11

Frequency of Annual Occurrence

Open-Ocean Deep Water

Northern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = 190° - 199°

Significant Wave Height, ft	Wave Period, sec				
	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9
0.0-0.9					
1.0-1.9					
2.0-2.9		0.1	0.1		
3.0-3.9					
4.0-4.9					
5.0-5.9					
6.0-7.9					
8.0-9.9					

These data are Station A data from "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Marine Advisers, January 1961.

Table G12

Frequency of Annual Occurrence

Open-Ocean Deep Water

Northern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = 200° - 209°

Significant Wave Height, ft	Wave Period, sec 8-9.9	10-11.9	12-13.9	14-15.9	16-17.9
0.0-0.9					
1.0-1.9			0.1		
2.0-2.9			0.1		
3.0-3.9					
4.0-4.9					
5.0-5.9					
6.0-7.9					
8.0-9.9					

These data are Station A data from "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Marine Advisers, January 1961.

Table G13

Frequency of Annual Occurrence

Open-Ocean Deep Water

Northern Hemisphere Swell Characteristics

(Frequency in Percent of Year)

Deepwater Approach Azimuth = 259^{o} - 281^{o}

Significant Wave Height, ft	Wave Period, sec						
	6-7.9	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9	18+
1.0-1.9	0.02	0.48	0.23	0.02	0.05		
2.0-2.9	0.88	2.07	1.06	0.62	0.35	0.11	0.02
3.0-3.9	0.42	0.87	0.50	0.35	0.02	0.09	0.02
4.0-4.9	0.16	0.48	0.23	0.09	0.12	0.02	
5.0-5.9	0.12	0.28	0.32	0.14	0.10		
6.0-6.9		0.31	0.32	0.12	0.07	0.05	
7.0-8.9		0.22	0.32	0.20	0.02		
9.0-10.9		0.02	0.23	0.16	0.10		
11.0-12.9			0.17	0.02	0.07	0.02	
13.0-14.9			0.05	0.09			
15.0-16.9							

These data are Station 7 data from "Wave Statistics for Seven Deep Water Stations Along the California Coast," National Marine Consultants, December 1960.

APPENDIX H: ANNUAL POTENTIAL LONGSHORE TRANSPORT SURFSIDE-SUNSET BEACH REGION, CALIFORNIA

Table H1

SURFSIDE-SUNSET BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Southern Hemisphere Swell Characteristics

Sheltered Deepwater Approach Azimuth = 180°

Significant Wave Height, ft		Wave Period, sec				
		12-13.9	14-15.9	16-17.9	18-19.9	20+
0.0-0.9	T =	5.0	3.6	2.1	0.2	0.1
	H_b =	1.0	1.0	1.0	1.0	1.0
	a_b =	+7.5	+8.2	+8.7	+9.3	+10.0
	Q =	+3151	+2480	+1535	+156	+84
1.0-1.9	T =	10.6	8.3	3.7	0.5	0.2
	H_b =	2.2	2.2	2.2	2.1	2.1
	a_b =	+9.7	+10.0	+10.2	+10.8	+11.1
	Q =	+62018	+50063	+22764	+2900	+1192
2.0-2.9	T =	0.3	0.2	0.1		
	H_b =	3.3	3.2	3.2		
	a_b =	+11.6	+11.7	+11.9		
	Q =	+5784	+3601	+1832		
3.0-3.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table H2

SURFSIDE-SUNSET BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Northern Hemisphere Swell Characteristics

Sheltered Deepwater Approach Azimuth = 180°

Significant Wave Height, ft		Wave Period, sec				
		8-9.9	10-11.9	12-13.9	14-15.9	16-17.9
0.0-0.9						
1.0-1.9	T =	0.2	0.4	0.3		
	H_b =	2.1	2.2	2.2		
	a_b =	+12.0	+10.7	+9.7		
	Q =	+1289	+2582	+1755		
2.0-2.9	T =			0.1	0.1	
	H_b =			3.3	3.2	
	a_b =			+11.6	+11.7	
	Q =			+1928	+1801	
3.0-3.9	T =				0.1	0.1
	H_b =				4.3	4.2
	a_b =				+13.2	+13.2
	Q =				+4252	+4009

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table H5

SURFSIDE-SUNSET BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Northern Hemisphere Swell Characteristics

Deepwater Approach Azimuth = 270°

Significant Wave Height, ft		Wave Period, sec						
		6-7.9	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9	18+
1.0-1.9	T =	0.02	0.48	0.23	0.02	0.05		
	H_b =	1.9	1.9	1.9	1.9	1.9		
	a_b =	-10.0	-6.7	-3.2	-1.2	-0.9		
	Q =	-84	-1345	-308	-10	-19		
2.0-2.9	T =	0.88	2.07	1.06	0.62	0.35	0.11	0.02
	H_b =	2.9	2.9	2.9	2.9	2.9	2.9	2.9
	a_b =	-12.5	-8.5	-4.4	-2.0	-1.3	-0.8	-0.5
	Q =	-13236	-21172	-5612	-1492	-548	-106	-12
3.0-3.9	T =	0.42	0.87	0.50	0.35	0.02	0.09	0.02
	H_b =	3.8	3.8	3.7	3.7	3.8	3.8	3.8
	a_b =	-14.5	-9.9	-5.3	-2.6	-1.7	-1.0	-0.5
	Q =	-14403	-20370	-5863	-2013	-80	-213	-24
4.0-4.9	T =	0.16	0.48	0.23	0.09	0.12	0.02	
	H_b =	4.7	4.7	4.6	4.6	4.7	4.7	
	a_b =	-15.7	-10.8	-5.9	-3.0	-2.0	-1.2	
	Q =	-10108	-20859	-5174	-1030	-966	-97	
5.0-5.9	T =	0.12	0.28	0.32	0.14	0.10		
	H_b =	5.8	5.8	5.7	5.7	5.7		
	a_b =	-16.7	-11.6	-6.3	-3.3	-2.2		
	Q =	-13641	-22109	-13139	-3011	-1434		
6.0-6.9	T =		0.31	0.32	0.12	0.07	0.05	
	H_b =		6.4	6.3	6.3	6.3	6.3	
	a_b =		-12.3	-6.8	-3.5	-2.3	-1.3	
	Q =		-33197	-18214	-3515	-1348	-544	

(Continued)

Table H3

(Continued)

Significant Wave Height, ft		Wave Period, sec 6-7.9	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9	18+
7.0-8.9	T =		0.22	0.32	0.20	0.02		
	H_b =		7.5	7.4	7.4	7.4		
	a_b =		-13.1	-7.3	-3.8	-2.4		
	Q =		-37302	-29237	-9512	-601		
9.0-10.9	T =		0.02	0.23	0.16	0.10		
	H_b =		9.1	8.9	8.9	9.0		
	a_b =		-14.2	-8.0	-4.3	-2.7		
	Q =		-5961	-36532	-13660	-5513		
11.0-12.9	T =			0.17	0.02	0.07	0.02	
	H_b =			10.4	10.3	10.3	10.3	
	a_b =			-8.5	-4.5	-2.8	-1.3	
	Q =			-42348	-2575	-5607	-744	
13.0-14.9	T =			0.05	0.09			
	H_b =			11.6	11.5			
	a_b =			-9.0	-4.8			
	Q =			-17328	-16278			
15.0-16.9								

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table H4

SURFSIDE-SUNSET BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 157°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T = H_b = a_b = Q =	1.21 0.5 +20.5 +368				
1.0-1.9	T = H_b = a_b = Q =	0.48 1.1 +27.0 +1382				
2.0-2.9	T = H_b = a_b = Q =	0.15 1.7 +33.0 +1567	0.06 2.3 +25.2 +1019			
3.0-3.9	T = H_b = a_b = Q =		0.13 3.1 +28.7 +5304			
4.0-4.9	T = H_b = a_b = Q =		0.03 3.9 +31.3 +2370			
5.0-5.9	T = H_b = a_b = Q =		0.03 4.7 +33.7 +4068	0.01 5.1 +26.5 +1308		

(Continued)

Table H4

(Continued)

Significant Wave Height, ft		Wave Period, sec 2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T = H_b = a_b = Q =			0.02 6.3 +28.3 +4738		
8.0-9.9	T = H_b = a_b = Q =			0.01 8.0 +31.6 +4806		
10.0-11.9						
12.0-13.9						
14.0-15.9	T = H_b = a_b = Q =					0.01 12.4 +28.8 +13102

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table H5

SURFSIDE-SUNSET BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 180°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	4.18				
	H_b =	0.6				
	a_b =	+17.0				
	Q =	+1665				
1.0-1.9	T =	0.61	0.49	0.04		
	H_b =	1.4	1.7	1.9		
	a_b =	+22.0	+16.5	+13.0		
	Q =	+2615	+2560	+217		
2.0-2.9	T =	0.02	0.25	0.03		
	H_b =	2.1	2.6	2.9		
	a_b =	+22.0	+20.0	+15.7		
	Q =	+236	+4579	+567		
3.0-3.9	T =		0.15			
	H_b =		3.6			
	a_b =		+23.0			
	Q =		+7128			
4.0-4.9	T =		0.12			
	H_b =		4.5			
	a_b =		+25.0			
	Q =		+10828			
5.0-5.9	T =			0.05		
	H_b =			5.4		
	a_b =			+21.5		
	Q =			+6120		

(Continued)

Table H5

(Continued)

Significant Wave Height, ft		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
		Wave Period, sec				
6.0-7.9	T =			0.06		
	H_b =			7.1		
	a_b =			+23.5		
	Q =			+15913		
8.0-9.9	T =			0.03		
	H_b =			9.0		
	a_b =			+25.5		
	Q =			+15619		
10.0-11.9	T =				0.03	
	H_b =				11.0	
	a_b =				+24.2	
	Q =				+24480	
12.0-13.9	T =				0.01	
	H_b =				12.6	
	a_b =				+25.6	
	Q =				+12121	
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table H6

SURFSIDE-SUNSET BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 202°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T = H_b = a_b = Q =	0.28 0.7 +9.5 +92				
1.0-1.9	T = H_b = a_b = Q =	0.13 1.5 +12.5 +376	0.01 1.9 +9.7 +41	0.26 2.2 +8.0 +1255		
2.0-2.9	T = H_b = a_b = Q =		0.08 2.9 +11.6 +1117			
3.0-3.9	T = H_b = a_b = Q =		0.06 3.8 +13.2 +1873			
4.0-4.9	T = H_b = a_b = Q =		0.03 4.8 +14.5 +1845			
5.0-5.9	T = H_b = a_b = Q =			0.01 5.9 +12.7 +902		

(Continued)

Table H6

(Continued)

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T = H_b = a_b = Q =			0.02 7.3 +13.7 +3315		
8.0-9.9	T = H_b = a_b = Q =			0.02 9.1 +15.0 +6297		
10.0-11.9	T = H_b = a_b = Q =				0.01 10.7 +14.8 +4657	
12.0-13.9	T = H_b = a_b = Q =				0.01 12.3 +15.7 +6999	
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table H7

SURFSIDE-SUNSET BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 225°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T = H_b = a_b = Q =	4.94 0.7 +1.3 +221				
1.0-1.9	T = H_b = a_b = Q =	1.12 1.5 +1.2 +311				
2.0-2.9	T = H_b = a_b = Q =		0.38 2.9 +1.7 +777			
3.0-3.9	T = H_b = a_b = Q =		0.18 3.9 +1.8 +818			
4.0-4.9	T = H_b = a_b = Q =		0.11 4.9 +2.0 +982			
5.0-5.9	T = H_b = a_b = Q =		0.03 5.8 +2.1 +429			

(Continued)

Table H7

(Continued)

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T = H_b = a_b = Q =			0.05 7.3 +3.2 +1936		
8.0-9.9						
10.0-11.9						
12.0-13.9						
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table H8

SURFSIDE-SUNSET BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth 247°

Significant Wave Height, ft		Wave Period, sec 2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	2.01				
	H_b =	0.8				
	a_b =	-7.5				
	Q =	-725				
1.0-1.9	T =	0.33		0.27	0.08	
	H_b =	1.6		2.2	2.4	
	a_b =	-10.5		-4.6	-1.4	
	Q =	-943		-749	-84	
2.0-2.9	T =	0.14			0.04	0.03
	H_b =	2.4			3.6	3.9
	a_b =	-12.8			-2.0	+1.3
	Q =	-1344			-165	+98
3.0-3.9	T =		0.12			
	H_b =		4.0			
	a_b =		-10.4			
	Q =		-3355			
4.0-4.9	T =		0.01			
	H_b =		4.9			
	a_b =		-11.2			
	Q =		-500			

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table H9

SURFSIDE-SUNSET BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 270°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	15.53				
	H_b =	0.7				
	a_b =	-15.4				
	Q =	-8238				
1.0-1.9	T =	2.53		1.91	0.53	0.03
	H_b =	1.4		1.9	1.9	1.9
	a_b =	-20.7		-10.0	-6.7	-3.2
	Q =	-10205		-7986	-1485	-40
2.0-2.9	T =		1.03		0.21	0.17
	H_b =		2.8		2.9	2.9
	a_b =		-18.5		-8.5	-4.5
	Q =		-21003		-2148	-921
3.0-3.9	T =		0.52			
	H_b =		3.6			
	a_b =		-20.9			
	Q =		-22454			
4.0-4.9	T =		0.35			
	H_b =		4.5			
	a_b =		-22.6			
	Q =		-28549			
5.0-5.9	T =			0.13		
	H_b =			5.6		
	a_b =			-16.7		
	Q =			-13537		

(Continued)

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LITTORAL PROCESSES STUDY, VICINITY OF SANTA ANA RIVER MOUTH FRO--ETC(U)
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Table H9

(Continued)

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T =			0.12		
	H_b =			6.9		
	a_b =			-18.1		
	Q =			-22823		
8.0-9.9	T =			0.03		
	H_b =			8.6		
	a_b =			-19.6		
	Q =			-10715		
10.0-11.9	T =				0.02	
	H_b =				10.0	
	a_b =				-14.6	
	Q =				-7758	
12.0-13.9						
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

APPENDIX I: ANNUAL POTENTIAL LONGSHORE TRANSPORT SANTA ANA RIVER MOUTH REGION, CALIFORNIA

Table I1

SANTA ANA RIVER MOUTH REGION, CALIFORNIA

Annual Potential Longshore Transport

Southern Hemisphere Swell Characteristics

Sheltered Deepwater Approach Azimuth = 180^{o}

Significant Wave Height, ft		Wave Period, sec				
		12-13.9	14-15.9	16-17.9	18-19.9	20+
0.0-0.9	T =	6.6	4.1	2.1	0.4	0.1
	H_b =	1.3	1.3	1.3	1.2	1.2
	a_b =	+7.4	+7.2	+7.0	+6.7	+6.4
	Q =	+7907	+4779	+2380	+355	+85
1.0-1.9	T =	11.6	9.2	4.0	0.6	0.2
	H_b =	2.7	2.7	2.6	2.6	2.5
	a_b =	+9.3	+9.1	+8.9	+8.6	+8.3
	Q =	+108576	+84261	+32604	+4726	+1378
2.0-2.9	T =	1.0	1.1	0.4	0.1	
	H_b =	4.0	4.0	3.9	3.9	
	a_b =	+11.1	+10.9	+10.6	+10.3	
	Q =	+29844	+32237	+10700	+2599	
3.0-3.9						

Legend

Time (Percent of Year)
Breaker Height, H_b , ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table I2

SANTA ANA RIVER MOUTH REGION, CALIFORNIA

Annual Potential Longshore Transport

Northern Hemisphere Swell Characteristics

Sheltered Deepwater Approach Azimuth = 180°

Significant Wave Height, ft		Wave Period, sec 8-9.9	10-11.9	12-13.9	14-15.9	16-17.9
0.0-0.9						
1.0-1.9	T =	0.2	0.2	0.1		
	H_b =	2.3	2.6	2.7		
	a_b =	+10.0	+9.5	+9.3		
	Q =	+1348	+1740	+936		
2.0-2.9	T =		0.2	0.4	0.2	0.1
	H_b =		3.9	4.0	4.0	4.0
	a_b =		+11.5	+11.1	+10.9	+10.3
	Q =		+5805	+11938	+5861	+2769
3.0-3.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table I3

SANTA ANA RIVER MOUTH REGION, CALIFORNIA

Annual Potential Longshore Transport

Northern Hemisphere Swell Characteristics

Deepwater Approach Azimuth = 270°

Significant Wave Height, ft		Wave Period, sec 6-7.9	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9	18+
1.0-1.9	T =	0.02	0.48	0.23	0.02	0.05		
	H_b =	1.7	1.5	1.4	1.4	1.6		
	a_b =	-15.9	-11.4	-6.7	-4.0	-2.8		
	Q =	-101	-1267	-300	-16	-38		
2.0-2.9	T =	0.88	2.07	1.06	0.62	0.35	0.11	0.02
	H_b =	2.6	2.4	2.0	2.0	2.4	2.7	2.9
	a_b =	-18.2	-13.0	-7.7	-4.6	-3.2	-1.9	-1.3
	Q =	-14668	-20176	-3879	-1356	-840	-210	-31
3.0-3.9	T =	0.42	0.87	0.50	0.35	0.02	0.09	0.02
	H_b =	3.5	3.0	2.7	2.7	3.0	3.5	3.8
	a_b =	-20.2	-14.3	-8.5	-5.0	-3.5	-1.9	-1.3
	Q =	-16336	-16295	-4277	-1761	-92	-329	-61
4.0-4.9	T =	0.16	0.48	0.23	0.09	0.12	0.02	
	H_b =	4.4	3.8	3.3	3.3	3.8	4.2	
	a_b =	-21.5	-15.3	-9.2	-5.3	-3.7	-2.0	
	Q =	-11737	-17369	-3517	-793	-1050	-121	
5.0-5.9	T =	0.12	0.28	0.32	0.14	0.10		
	H_b =	5.2	4.6	3.9	3.9	4.5		
	a_b =	-22.7	-16.2	-9.7	-5.7	-3.8		
	Q =	-14112	-17296	-7834	-2014	-1372		
6.0-6.9	T =		0.31	0.32	0.12	0.07	0.05	
	H_b =		5.3	4.5	4.5	5.1	5.7	
	a_b =		-17.0	-10.1	-5.9	-4.0	-2.2	
	Q =		-28634	-11665	-2555	-1382	-717	

(Continued)

Table I3

(Continued)

Significant Wave Height, ft		Wave Period, sec						
		6-7.9	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9	18+
7.0-8.9	T =		0.22	0.32	0.20	0.02		
	H_b =		6.3	5.4	5.3	6.0		
	a_b =		-18.1	-10.7	-6.2	-4.2		
	Q =		-33330	-19494	-6737	-622		
9.0-10.9	T =		0.02	0.23	0.16	0.10		
	H_b =		7.7	6.4	6.3	7.2		
	a_b =		-19.3	-11.3	-6.4	-4.3		
	Q =		-5336	-22628	-8571	-5026		
11.0-12.9	T =			0.17	0.02	0.07	0.02	
	H_b =			7.5	7.4	8.4	9.4	
	a_b =			-11.9	-6.6	-4.5	-2.7	
	Q =			-26184	-1652	-5412	-1229	
13.0-14.9	T =			0.05	0.09			
	H_b =			8.4	8.1			
	a_b =			-12.3	-6.8			
	Q =			-10567	-9602			
15.0-16.9								

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table I4

SANTA ANA RIVER MOUTH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 157°

Significant Wave Height, ft		Wave Period, sec 2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T = H_b = a_b = Q =	1.21 0.6 +15.5 +435				
1.0-1.9	T = H_b = a_b = Q =	0.48 1.3 +22.3 +1742				
2.0-2.9	T = H_b = a_b = Q =	0.15 2.0 +28.2 +2010	0.06 2.3 +20.8 +841			
3.0-3.9	T = H_b = a_b = Q =		0.13 3.1 +24.0 +4436			
4.0-4.9	T = H_b = a_b = Q =		0.03 3.8 +26.3 +1866			
5.0-5.9	T = H_b = a_b = Q =		0.03 4.7 +28.3 +3416	0.01 4.9 +21.7 +969		

(Continued)

Table I4

(Continued)

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T =			0.02		
	H_b =			6.1		
	a_b =			+24.0		
	Q =			+3706		
8.0-9.9	T =			0.01		
	H_b =			7.6		
	a_b =			+26.7		
	Q =			+3572		
10.0-11.9						
12.0-13.9						
14.0-15.9	T =					0.01
	H_b =					12.5
	a_b =					+28.5
	Q =					+13228

<u>Legend</u>

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table 15

SANTA ANA RIVER MOUTH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 180°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	4.18				
	H_b =	0.7				
	a_b =	+12.5				
	Q =	+1800				
1.0-1.9	T =	0.61	0.49	0.04		
	H_b =	1.5	1.8	2.2		
	a_b =	+17.0	+12.5	+10.0		
	Q =	+2401	+2237	+241		
2.0-2.9	T =	0.02	0.25	0.03		
	H_b =	2.3	2.7	3.1		
	a_b =	+20.7	+15.3	+12.2		
	Q =	+279	+3850	+520		
3.0-3.9	T =		0.15			
	H_b =		3.6			
	a_b =		+17.5			
	Q =		+5423			
4.0-4.9	T =		0.12			
	H_b =		4.5			
	a_b =		+19.2			
	Q =		+8316			
5.0-5.9	T =			0.05		
	H_b =			6.2		
	a_b =			+16.7		
	Q =			+6715		

(Continued)

Table I5

(Continued)

Significant Wave Height, ft		Wave Period, sec 2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T =			0.06		
	H_b =			7.4		
	a_b =			+18.3		
	Q =			+13743		
8.0-9.9	T =			0.03		
	H_b =			9.3		
	a_b =			+20.0		
	Q =			+13297		
10.0-11.9	T =				0.03	
	H_b =				12.0	
	a_b =				+20.8	
	Q =				+26153	
12.0-13.9	T =				0.01	
	H_b =				13.7	
	a_b =				+22.0	
	Q =				+12841	
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table I6

SANTA ANA RIVER MOUTH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 202°

Significant Wave Height, ft		Wave Period, sec 2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	0.28				
	H_b =	0.7				
	a_b =	+3.3				
	Q =	+32				
1.0-1.9	T =	0.13	0.01	0.26		
	H_b =	1.5	1.9	2.2		
	a_b =	+5.7	+3.7	+3.4		
	Q =	+172	+15	+533		
2.0-2.9	T =		0.08			
	H_b =		2.8			
	a_b =		+5.0			
	Q =		+441			
3.0-3.9	T =		0.06			
	H_b =		3.8			
	a_b =		+6.0			
	Q =		+851			
4.0-4.9	T =		0.03			
	H_b =		4.7			
	a_b =		+6.8			
	Q =		+821			
5.0-5.9	T =			0.01		
	H_b =			6.3		
	a_b =			+6.7		
	Q =			+561		

(Continued)

Table I6

(Continued)

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T =			0.02		
	H_b =			7.7		
	a_b =			+7.5		
	Q =			+2073		
8.0-9.9	T =			0.02		
	H_b =			9.5		
	a_b =			+8.3		
	Q =			+3880		
10.0-11.9	T =				0.01	
	H_b =				12.5	
	a_b =				+9.6	
	Q =				+4456	
12.0-13.9	T =				0.01	
	H_b =				14.2	
	a_b =				+10.0	
	Q =				+6384	
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table I7

SANTA ANA RIVER MOUTH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 225°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	4.94				
	H_b =	0.7				
	a_b =	-5.8				
	Q =	-987				
1.0-1.9	T =	1.12				
	H_b =	1.5				
	a_b =	-6.7				
	Q =	-1737				
2.0-2.9	T =		0.38			
	H_b =		2.9			
	a_b =		-5.5			
	Q =		-2515			
3.0-3.9	T =		0.18			
	H_b =		3.9			
	a_b =		-5.8			
	Q =		-2635			
4.0-4.9	T =		0.11			
	H_b =		4.9			
	a_b =		-6.1			
	Q =		-2996			
5.0-5.9	T =		0.03			
	H_b =		5.8			
	a_b =		-6.3			
	Q =		-1287			

(Continued)

Table I7

(Continued)

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T = H_b = a_b = Q =			0.05 7.9 -4.5 -3316		
8.0-9.9						
10.0-11.9						
12.0-13.9						
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table I8

SANTA ANA RIVER MOUTH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 247°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	2.01				
	H_b =	0.7				
	a_b =	-13.5				
	Q =	-935				
1.0-1.9	T =	0.33		0.27	0.08	
	H_b =	1.5		2.1	2.3	
	a_b =	-17.1		-10.4	-8.2	
	Q =	-1307		-1508	-442	
2.0-2.9	T =	0.14			0.04	0.03
	H_b =	2.3			3.4	3.6
	a_b =	-20.2			-9.0	-6.4
	Q =	-1906			-645	-397
3.0-3.9	T =		0.12			
	H_b =		3.8			
	a_b =		-17.2			
	Q =		-4882			
4.0-4.9	T =		0.01			
	H_b =		4.7			
	a_b =		-18.4			
	Q =		-740			

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table I9

SANTA ANA RIVER MOUTH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 270°

Significant Wave Height, ft		Wave Period, sec 2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	15.53				
	H_b =	0.7				
	a_b =	-20.5				
	Q =	-10966				
1.0-1.9	T =	2.53		1.91	0.53	0.03
	H_b =	1.4		1.7	1.5	1.4
	a_b =	-27.0		-15.9	-11.3	-6.1
	Q =	-13310		-9615	-1387	-36
2.0-2.9	T =		1.03		0.21	0.17
	H_b =		2.6		2.4	2.0
	a_b =		-24.5		-13.0	-7.7
	Q =		-23111		-2047	-622
3.0-3.9	T =		0.52			
	H_b =		3.5			
	a_b =		-27.2			
	Q =		-27235			
4.0-4.9	T =		0.35			
	H_b =		4.4			
	a_b =		-29.3			
	Q =		-34991			
5.0-5.9	T =			0.13		
	H_b =			5.2		
	a_b =			-22.7		
	Q =			-15288		

(Continued)

Table I9

(Continued)

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T =			0.12		
	H_b =			6.5		
	a_b =			-24.4		
	Q =			-26500		
8.0-9.9	T =			0.03		
	H_b =			8.2		
	a_b =			-26.4		
	Q =			-12813		
10.0-11.9	T =				0.02	
	H_b =				8.2	
	a_b =				-28.3	
	Q =				-9157	
12.0-13.9						
14.0-15.9						

<u>Legend</u>

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table I10

SANTA ANA RIVER MOUTH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 292°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T = H_b = a_b = Q =	1.33 0.4 -18.3 -207				
1.0-1.9	T = H_b = a_b = Q =	0.70 0.9 -25.8 -1166				
2.0-2.9	T = H_b = a_b = Q =		0.35 2.0 -24.4 -4059			
3.0-3.9	T = H_b = a_b = Q =		0.21 2.7 -28.0 -5918			
4.0-4.9	T = H_b = a_b = Q =		0.16 3.5 -30.3 -9335			
5.0-5.9	T = H_b = a_b = Q =			0.08 4.3 -24.1 -6211		

(Continued)

Table I10

(Continued)

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T = H_b = a_b = Q =			0.08 5.3 -26.3 -11432		
8.0-9.9	T = H_b = a_b = Q =			0.01 6.7 -29.0 -2831		
10.0-11.9						
12.0-13.9						
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd /year

APPENDIX J: ANNUAL POTENTIAL LONGSHORE TRANSPORT NEWPORT BEACH REGION, CALIFORNIA

Table J1

NEWPORT BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Southern Hemisphere Swell Characteristics

Sheltered Deepwater Approach Azimuth = 180°

Significant Wave Height, ft		Wave Period, sec				
		12-13.9	14-15.9	16-17.9	18-19.9	20+
0.0-0.9	T =	7.2	4.4	2.1	0.4	0.1
	H_b =	1.1	1.3	1.4	1.5	1.6
	a_b =	+6.7	+5.7	+4.8	+4.0	+3.5
	Q =	+5144	+4060	+1964	+370	+95
1.0-1.9	T =	12.8	10.0	4.1	0.6	0.2
	H_b =	2.5	2.7	2.8	2.9	3.0
	a_b =	+7.5	+6.7	+5.5	+4.8	+4.5
	Q =	+79709	+67433	+24856	+3466	+1179
2.0-2.9	T =	1.6	2.0	0.7	0.1	
	H_b =	3.9	4.0	4.2	4.4	
	a_b =	+8.5	+7.5	+6.5	+5.7	
	Q =	+34323	+40330	+13820	+1945	
3.0-3.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft.
Breaker Angle, a_b, deg.
Potential Longshore Transport, cu yd/year

Table J2

NEWPORT BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Northern Hemisphere Swell Characteristics

Sheltered Deepwater Approach Azimuth = 180^{o}

Significant Wave Height, ft		Wave Period, sec				
		8-9.9	10-11.9	12-13.9	14-15.9	16-17.9
0.0-0.9						
1.0-1.9	T =	0.3	0.2	0.1		
	H_b =	2.2	2.4	2.5		
	a_b =	+7.5	+7.7	+7.5		
	Q =	+1357	+1155	+623		
2.0-2.9	T =	0.1	0.4	0.2	0.1	0.1
	H_b =	3.3	3.7	3.9	4.0	4.2
	a_b =	+8.8	+8.8	+8.5	+7.5	+6.5
	Q =	+1463	+7788	+4290	+2016	+1974
3.0-3.9	T =				0.1	
	H_b =				5.4	
	a_b =				+8.2	
	Q =				+4669	

Legend

Time (Percent of Year)

Breaker Height, H_b, ft

Breaker Angle, a_b, deg

Potential Longshore Transport, cu yd/year

Table J3

NEWPORT BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Northern Hemisphere Swell Characteristics

Deepwater Approach Azimuth = 270°

Significant Wave Height, ft		Wave Period, sec						
		6-7.9	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9	18+
1.0-1.9	T =	0.02	0.48	0.23	0.02	0.05		
	H_b =	1.3	1.3	1.3	1.3	1.3		
	a_b =	-12.3	-10.6	-9.3	-9.2	-9.8		
	Q =	-40	-824	-346	-30	-79		
2.0-2.9	T =	0.88	2.07	1.06	0.62	0.35	0.11	0.02
	H_b =	2.2	2.1	2.0	2.0	1.9	1.9	1.9
	a_b =	-15.0	-12.7	-10.7	-10.1	-10.6	-11.0	-11.5
	Q =	-7962	-14116	-5391	-2976	-1551	-506	-96
3.0-3.9	T =	0.42	0.87	0.50	0.35	0.02	0.09	0.02
	H_b =	2.9	2.7	2.5	2.5	2.5	2.5	2.5
	a_b =	-12.3	-14.5	-12.0	-10.8	-11.3	-11.7	-12.0
	Q =	-6216	-12696	-4982	-3139	-188	-874	-199
4.0-4.9	T =	0.16	0.48	0.23	0.09	0.12	0.02	
	H_b =	3.7	3.4	3.1	3.1	3.1	3.0	
	a_b =	-19.2	-16.0	-12.9	-11.5	-11.8	-12.2	
	Q =	-6797	-13754	-4218	-1471	-2013	-320	
5.0-5.9	T =	0.12	0.28	0.32	0.14	0.10		
	H_b =	4.4	4.1	3.7	3.6	3.6		
	a_b =	-20.7	-17.2	-13.7	-12.2	-12.4		
	Q =	-8476	-13773	-9700	-3529	-2562		
6.0-6.9	T =		0.31	0.32	0.12	0.07	0.05	
	H_b =		4.7	4.3	4.1	4.1	4.1	
	a_b =		-18.3	-14.5	-12.7	-12.8	-13.0	
	Q =		-22827	-14947	-4358	-2562	-1859	

(Continued)

Table J3

(Continued)

Significant Wave Height, ft		Wave Period, sec						
		6-7.9	8-9.9	10-11.9	12-13.9	14-15.9	16-17.9	18+
7.0-8.9	T =		0.22	0.32	0.20	0.02		
	H_b =		5.6	5.1	4.8	4.8		
	a_b =		-19.8	-15.5	-13.3	-13.4		
	Q =		-27161	-24479	-11282	-1137		
9.0-10.9	T =		0.02	0.23	0.16	0.10		
	H_b =		6.8	6.2	5.8	5.8		
	a_b =		-21.5	-16.6	-14.2	-14.3		
	Q =		-4356	-30704	-15465	-9734		
11.0-12.9	T =			0.17	0.02	0.07	0.02	
	H_b =			7.1	6.7	6.7	6.7	
	a_b =			-17.7	-14.7	-14.7	-14.7	
	Q =			-33959	-2870	-10046	-2870	
13.0-14.9	T =			0.05	0.09			
	H_b =			7.9	7.5			
	a_b =			-18.5	-15.3			
	Q =			-13633	-17823			
15.0-16.9								

<u>Legend</u>

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table J4

NEWPORT BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 157°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	1.21				
	H_b =	0.7				
	a_b =	+18.0				
	Q =	+750				
1.0-1.9	T =	0.48				
	H_b =	1.4				
	a_b =	+23.1				
	Q =	+2161				
2.0-2.9	T =	0.15	0.06			
	H_b =	2.1	2.5			
	a_b =	+28.0	+20.7			
	Q =	+2255	+1031			
3.0-3.9	T =		0.13			
	H_b =		3.3			
	a_b =		+23.6			
	Q =		+5099			
4.0-4.9	T =		0.03			
	H_b =		4.2			
	a_b =		+25.7			
	Q =		+2342			
5.0-5.9	T =		0.03	0.01		
	H_b =		5.0	5.4		
	a_b =		+27.5	+21.2		
	Q =		+3875	+1207		

(Continued)

Table J4

(Continued)

Significant Wave Height, ft		Wave Period, sec 2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T =			0.02		
	H_b =			6.6		
	a_b =			+23.0		
	Q =			+4325		
8.0-9.9	T =			0.01		
	H_b =			8.2		
	a_b =			+25.2		
	Q =			+4077		
10.0-11.9						
12.0-13.9						
14.0-15.9	T =					0.01
	H_b =					14.0
	a_b =					+21.3
	Q =					+13125

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table J5

NEWPORT BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 180°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	4.18				
	H_b =	0.7				
	a_b =	+9.2				
	Q =	+1325				
1.0-1.9	T =	0.61	0.49	0.04		
	H_b =	1.5	1.8	2.0		
	a_b =	+12.3	+8.9	+7.2		
	Q =	+1737	+1593	+137		
2.0-2.9	T =	0.02	0.25	0.03		
	H_b =	2.3	2.7	3.0		
	a_b =	+15.3	+11.0	+8.7		
	Q =	+206	+2768	+342		
3.0-3.9	T =		0.15			
	H_b =		3.6			
	a_b =		+12.6			
	Q =		+3905			
4.0-4.9	T =		0.12			
	H_b =		4.5			
	a_b =		+14.0			
	Q =		+6064			
5.0-5.9	T =			0.05		
	H_b =			5.9		
	a_b =			+11.8		
	Q =			+4191		

(Continued)

Table J5

(Continued)

Significant Wave Height, ft		Wave Period, sec 2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T =			0.06		
	H_b =			7.2		
	a_b =			+13.0		
	Q =			+9116		
8.0-9.9	T =			0.03		
	H_b =			8.9		
	a_b =			+14.3		
	Q =			+8518		
10.0-11.9	T =				0.03	
	H_b =				11.4	
	a_b =				+14.3	
	Q =				+15816	
12.0-13.9	T =				0.01	
	H_b =				13.2	
	a_b =				+15.2	
	Q =				+8085	
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table J6

NEWPORT BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 202°

Significant Wave Height, ft		Wave Period, sec 2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	0.28				
	H_b =	0.7				
	a_b =	+1.2				
	Q =	+12				
1.0-1.9	T =	0.13	0.01	0.26		
	H_b =	1.5	1.9	2.2		
	a_b =	+1.9	+1.5	+1.5		
	Q =	+57	+6	+235		
2.0-2.9	T =		0.08			
	H_b =		2.9			
	a_b =		+2.3			
	Q =		+221			
3.0-3.9	T =		0.06			
	H_b =		3.8			
	a_b =		+2.8			
	Q =		+397			
4.0-4.9	T =		0.03			
	H_b =		4.7			
	a_b =		+3.2			
	Q =		+386			
5.0-5.9	T =			0.01		
	H_b =			6.2		
	a_b =			+3.4		
	Q =			+273		

(Continued)

Table J6

(Continued)

Significant Wave Height, ft		Wave Period, sec 2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T =			0.02		
	H_b =			7.3		
	a_b =			+3.5		
	Q =			+847		
8.0-9.9	T =			0.02		
	H_b =			9.4		
	a_b =			+3.7		
	Q =			+1684		
10.0-11.9	T =				0.01	
	H_b =				11.9	
	a_b =				+3.7	
	Q =				+1519	
12.0-13.9	T =				0.01	
	H_b =				13.6	
	a_b =				+3.7	
	Q =				+2120	
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table J7

NEWPORT BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 225°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T = H_b = a_b = Q =	4.94 0.7 -7.2 -1225				
1.0-1.9	T = H_b = a_b = Q =	1.12 1.5 -9.5 -2464				
2.0-2.9	T = H_b = a_b = Q =		0.38 2.7 -8.2 -3136			
3.0-3.9	T = H_b = a_b = Q =		0.18 3.7 -9.3 -3704			
4.0-4.9	T = H_b = a_b = Q =		0.11 4.6 -10.2 -4278			
5.0-5.9	T = H_b = a_b = Q =		0.03 5.5 -10.8 -1931			

(Continued)

Table J7

(Continued)

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T = H_b = a_b = Q =			0.05 7.4 -8.7 -5444		
8.0-9.9						
10.0-11.9						
12.0-13.9						
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table J8

NEWPORT BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 247°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	2.01				
	H_b =	0.7				
	a_b =	-16.2				
	Q =	-1122				
1.0-1.9	T =	0.33		0.27	0.08	
	H_b =	1.4		1.9	2.0	
	a_b =	-20.0		-10.0	-8.8	
	Q =	-1286		-1129	-335	
2.0-2.9	T =	0.14			0.04	0.03
	H_b =	2.2			3.0	3.2
	a_b =	-23.6			-10.2	-9.2
	Q =	-1993			-534	-425
3.0-3.9	T =		0.12			
	H_b =		3.5			
	a_b =		-18.6			
	Q =		-4298			
4.0-4.9	T =		0.01			
	H_b =		4.4			
	a_b =		-20.3			
	Q =		-693			

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table J9

NEWPORT BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 270°

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	15.53				
	H_b =	0.6				
	a_b =	-16.0				
	Q =	-5822				
1.0-1.9	T =	2.53		1.91	0.53	0.03
	H_b =	1.3		1.5	1.4	1.3
	a_b =	-23.0		-12.2	-10.7	-9.3
	Q =	-9421		-5395	-1105	-45
2.0-2.9	T =		1.03		0.21	0.17
	H_b =		2.3		2.2	2.1
	a_b =		-20.5		-12.7	-10.7
	Q =		-14233		-1609	-977
3.0-3.9	T =		0.52			
	H_b =		3.0			
	a_b =		-24.0			
	Q =		-16346			
4.0-4.9	T =		0.35			
	H_b =		3.8			
	a_b =		-27.0			
	Q =		-22350			
5.0-5.9	T =			0.13		
	H_b =			4.5		
	a_b =			-20.7		
	Q =			-9712		

(Continued)

Table J9

(Continued)

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T = H_b = a_b = Q =			0.12 5.5 -22.8 -16308		
8.0-9.9	T = H_b = a_b = Q =			0.03 6.8 -25.2 -7659		
10.0-11.9	T = H_b = a_b = Q =				0.02 7.4 -22.2 -5557	
12.0-13.9						
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

Table J10

NEWPORT BEACH REGION, CALIFORNIA

Annual Potential Longshore Transport

Sea Characteristics

Sheltered Deepwater Approach Azimuth = 292^{o}

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
0.0-0.9	T =	1.33				
	H_b =	0.3				
	a_b =	-15.2				
	Q =	-84				
1.0-1.9	T =	0.70				
	H_b =	0.6				
	a_b =	-20.0				
	Q =	-328				
2.0-2.9	T =		0.35			
	H_b =		1.2			
	a_b =		-16.7			
	Q =		-775			
3.0-3.9	T =		0.21			
	H_b =		1.5			
	a_b =		-19.2			
	Q =		-934			
4.0-4.9	T =		0.16			
	H_b =		1.9			
	a_b =		-21.5			
	Q =		-1438			
5.0-5.9	T =			0.08		
	H_b =			2.2		
	a_b =			-16.3		
	Q =			-787		

(Continued)

Table J10

(Continued)

Significant Wave Height, ft		Wave Period, sec				
		2-3.9	4-5.9	6-7.9	8-9.9	10-11.9
6.0-7.9	T =			0.08		
	H_b =			2.6		
	a_b =			-18.0		
	Q =			-1319		
8.0-9.9	T =			0.01		
	H_b =			3.3		
	a_b =			-19.8		
	Q =			-329		
10.0-11.9						
12.0-13.9						
14.0-15.9						

Legend

Time (Percent of Year)
Breaker Height, H_b, ft
Breaker Angle, a_b, deg
Potential Longshore Transport, cu yd/year

APPENDIX K: NOTATION

NOTATION

a_b	Breaking wave angle with shoreline, deg
a_o	Half-diurnal ocean tide, ft
A	Cross-sectional area of tidal inlet channel, ft^2
A_b	Average bay water-surface area, ft^2
C	Wave celerity, ft/sec
C_g	Propagation velocity of wave energy, ft/sec
d	Local water depth, ft
E	Wave energy density, $ft\text{-}lb/ft^2$
g	Gravitational constant, ft/sec^2
H	Wave height
H_b	Breaking wave height, ft
H_L	Total energy loss across a section, ft
H_o	Deepwater wave height, ft
H_{en}	Entrance energy loss, ft
H_{ex}	Exit energy loss, ft
H_{fl}	Frictional energy loss, ft
k	Wave number, $2\pi/L$, ft^{-1}
K	Keulegan repletion coefficient, dimensionless
K_{en}	Entrance energy loss coefficient, dimensionless
K_{eq}	Lumped parameter energy loss coefficient, dimensionless
K_{ex}	Exit energy loss coefficient, dimensionless
K_{fl}	Frictional energy loss coefficient, dimensionless
L	Pipe, channel, or wavelength, ft
m	Beach slope, ft/ft
n	Manning's roughness coefficient, $ft^{1/6}$
P	Bay tidal prism, ft^3
P_{ls}	Longshore component of wave energy flux, ft-lb/ft/sec
Q_{ls}	Longshore sediment transport, yd^3/yr
R	Hydraulic radius, ft
t	Time, sec
T	Wave period, sec
u	Horizontal fluid particle velocity, ft/sec

V	Average velocity of flow across a section, ft/sec
V_{ls}	Longshore current velocity, ft/sec
y	Depth below mean waterline, ft
η_b	Half-diurnal bay tide, ft
θ_{100}	Wave direction-of-approach in water depth of 100 fathoms, azimuth in degrees
ρ	Fluid density, lb-sec^2/ft^4
σ	Wave angular frequency, $2\pi/T$, sec^{-1}

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Hales, Lyndell Z

Littoral processes study, vicinity of Santa Ana River mouth from Anaheim Bay to Newport Bay, California / by Lyndell Z. Hales. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfiel', Va. : available from National Technical Information Service, 1980.

107, [121] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; HL-80-9)

Prepared for U. S. Army Engineer District, Los Angeles, Los Angeles, Calif.

References: p.105-107.

1. Beach erosion. 2. Beach nourishment. 3. Littoral deposits. 4. Santa Ana River. 5. Tidal effects. 6. Tidal marshes. I. United States. Army. Corps of Engineers. Los Angeles District. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; HL-80-9.

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